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THE

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AND

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The Mineralogical Society

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WITH A SEPARATELY-PAGED APPENDIX OF

MINERALOGICAL ABSTRACTS

EDITED BY L. J. SPENCER, F.R.S.

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PROCEEDINGS
OF THE
MINERALOGICAL SOCIETY

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., January 14, 1930, *at* 4 *p.m.*

Dr. G. T. Prior, F.R.S., President, in the Chair.

The resignations of Messrs. H. W. Monckton, G. W. Sneesby, and W. R. Storr were received and accepted.

The name of Mr. E. L. Johnson was ordered to be erased from the List of Members in accordance with Bye-law 7.

Prof. Frank Robertson Van Horn and Mr. Lawrence Rickard Wager were provisionally elected Ordinary Members of the Society.

Reported that owing to the illness of Mr. T. Crook, Mr. F. A. Bannister had been asked to act as auditor in his place for the accounts of 1929.

The audited accounts and balance-sheet for the year ending December 31, 1929, were presented by the Treasurer and approved.

The Treasurer was authorized to spend a sum not exceeding £15 on boxes for storing the stock of the Journal.

A letter was received from Dr. Viktor Zsivny, of Budapest, agreeing to abstract the Hungarian literature for 'Mineralogical Abstracts'.

The Librarian reported that the catalogue of separates in the Society's Library had been completed.

A letter was received from Mr. S. Henson acknowledging the President's congratulations on attaining his fiftieth year as a Member of the Society.

GENERAL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., January 14, 1930, *at* 5.30 *p.m.*

Dr. G. T. Prior, F.R.S., President, in the Chair.

Twenty-one Members and one Visitor were present.

The elections of Prof. F. R. Van Horn and Mr. L. R. Wager as Ordinary Members of the Society were confirmed.

Dr. L. J. Spencer read excerpts from the following papers :—

1. The occurrence of potassium nitrate near Goyder's Pass, McDonnell Ranges, Central Australia : by Sir Douglas Mawson (p. 231).

2. A new occurrence of zunyite near Postmasburg, South Africa : by Dr. L. T. Nel (p. 207).

In connexion with the second paper Dr. Spencer described some recent work of his own on the twinning of tetrahedral crystals, illustrating his remarks with paper models.

Mr. W. Campbell Smith exhibited lantern slides and thin sections of volcanic rocks from Kenya Colony. The thin sections were demonstrated by Mr. A. F. Hallimond with the aid of a small Leitz projection microscope kindly lent by H.M. Geological Survey.

Mr. F. N. Ashcroft exhibited fine specimens of minerals which he had recently collected at Broken Hill, Northern Rhodesia, and other localities.

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., March 18, 1930, *at* 4 *p.m.*

Dr. G. T. Prior, F.R.S., President, in the Chair.

Mr. Thomas Clifford Fitzwilliam Hall and Dr. Frederick Walker were provisionally elected Ordinary Members of the Society.

Letters were received from the Association of Scientific Workers referring to the financial position of the Science Library, and the President reported that he had attended a conference on this matter at the House of Commons on March 17.

GENERAL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., March 18, 1930, *at* 5.30 *p.m.*

Dr. G. T. Prior, F.R.S., President, in the Chair.

Twenty-eight Members and twenty-four Visitors were present.

The elections of Mr. T. C. F. Hall and Dr. F. Walker as Ordinary Members of the Society were confirmed.

Prof. W. L. Bragg then delivered a lecture on 'The structure of silicates', in which he presented in a masterly manner the results achieved by himself and his research students at Manchester. He showed how the oxygen atom, formerly almost taken as granted by the chemists in their analyses, determines by its size the pattern of both close-packed and open structures. The three chief types of structure are: (1) those in which chains of linked silicon–oxygen tetrahedra form the basis of the structure; (2) those in which the tetrahedra link up to form sheets, limited, curiously enough, to hexagonal patterns; and (3) those in which the tetrahedra form three-dimensional cage-like structures. He also drew attention to the importance of oxygen in silicate formulae, and the success with which the results of X-ray determinations have been applied to settling doubtful formulae, such as, for example, those of diopside and tremolite.

Sir Henry Miers and Prof. A. Hutchinson both paid eloquent tribute to the lecturer, expressing the indebtedness of the Society to him for giving to the Society this first account of his immensely important researches. A vote of thanks to the lecturer was put from the Chair and carried with acclamation.

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., June 3, 1930, *at* 4 *p.m.*

Dr. G. T. Prior, F.R.S., President, in the Chair.

Dr. William Richard Jones and Mr. Arthur Eric Jarvis Vickers were provisionally elected Ordinary Members of the Society.

The following changes in the list of Officers and Council were proposed: Sir John S. Flett to be President, and Prof. C. Gilbert Cullis to be a Vice-President. Ordinary Members of Council to be asked to stand for election: past members, Mr. A. F. Hallimond and Dr. F. H. Hatch; new members, Sir Albert E. Kitson and Prof. W. L. Bragg. The four senior Ordinary Members due to retire were Mr. A. J. Bull, Prof. C. Gilbert Cullis, Prof. Harold Hilton, and Dr. W. F. P. McLintock. The President, Dr. G. T. Prior, also retires on the completion of three years' service.

It was decided to hold the meetings in 1931 on the following dates : Tuesdays—January 13, March 17, June 9, November 3.

A letter was received from Prof. Henry Louis thanking the Society for their letter of congratulation on the completion of his fifty years of membership.

An invitation was received from the Congrès International des Mines, de la Métallurgie et de la Géologie appliquée to send a delegate, and Dr. W. F. P. McLintock was nominated to attend the sixth meeting on June 22–28, 1930, at Liége.

An invitation was received from the Société Géologique de France for the President, accompanied by a delegation, to be present at their Centenary Celebrations on June 30 and the following days. The President regretted his inability to attend. Prof. A. Hutchinson, the Treasurer, and the General Secretary were appointed as the Society's delegation, and it was decided to print a suitable address for presentation.

GENERAL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., June 3, 1930, *at* 5.30 *p.m.*

Dr. G. T. Prior, F.R.S., President, in the Chair.

Seventeen Members and four Visitors were present.

The elections of Dr. W. R. Jones and Mr. A. E. J. Vickers as Ordinary Members of the Society were confirmed.

The following papers were read :—

1. A new meteoric iron from Piedade do Bagre, Minas Geraes, Brazil : by Dr. L. J. Spencer (p. 271).

2. Notes on British barytes : by Miss Jessie M. Sweet (p. 257).

3. On face- and zone-symbols referred to hexagonal axes : by Mr. M. H. Hey (p. 283).

4. Biographical notices of mineralogists recently deceased (fourth series) : by Dr. L. J. Spencer (p. 387).

5. A tholeiitic phase of the quartz-dolerite magma of central Scotland : by Dr. F. Walker (p. 368).

6. On pink epsomites and fauserite : by Mr. M. H. Hey.

EXCERPT MINUTES OF COUNCIL MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., November 4, 1930, *at* 4 *p.m.*

Dr. G. T. Prior, F.R.S., President, in the Chair.

Prof. Shukusuké Kôzu, Prof. Béla Mauritz, and Mr. Herbert Marcus Powell were provisionally elected Ordinary Members of the Society.

The resignations of Mr. A. D. Lumb and L. Zutshi were received and accepted. The death of Mr. S. Henson on June 9, 1930, was announced.

Prof. C. G. Cullis and Mr. F. A. Bannister were elected auditors of the accounts for the year ending December 31, 1930.

Authority was given to have reprints made of p. 3 of the wrapper of the Magazine for distribution.

The Annual Report of the Council, submitted by the Secretary, was read and approved.

A letter was received from Dr. W. T. Schaller, and Sir John S. Flett, Sir Henry A. Miers, and Dr. L. J. Spencer (secretary) were appointed to form a committee on mineralogical nomenclature, to co-operate with the corresponding committee of the Mineralogical Society of America, and to report.

GENERAL (ANNIVERSARY) MEETING.

Held in the Apartments of the Geological Society, Burlington House, London, W., November 4, 1930, *at* 5.30 *p.m.*

Dr. G. T. Prior, F.R.S., and afterwards
Sir John S. Flett, K.B.E., F.R.S., President, in the Chair.

Thirty-six Members and five Visitors were present.

The President nominated Mr. F. A. Bannister and Mr. H. G. Smith to act as scrutineers of the voting-papers for the election of Officers and Council. The scrutineers reported that eighty-nine voting-papers had been returned to the Secretary, and that the list as nominated by the Council was approved, namely:—

President. Sir John S. Flett, K.B.E., M.A., LL.D., D.Sc., F.R.S.

Vice-Presidents. Dr. G. F. Herbert Smith, M.A., D.Sc., F.G.S., F.R.A.S.
Prof. C. Gilbert Cullis, D.Sc., F.G.S.

Treasurer. F. N. Ashcroft, M.A., F.G.S., F.C.S.

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Foreign Secretary. Dr. J. W. Evans, C.B.E., D.Sc., LL.B., F.R.S.

Editor of the Journal. Dr. L. J. Spencer, M.A., Sc.D., F.R.S.

Ordinary Members of Council.

Colonel N. T. Belaiew, C.B., F.C.S.
Harvey Collingridge, B.Sc., F.G.S.
Henry Dewey, F.G.S.
Prof. Arthur Holmes, D.Sc., F.G.S.
Dr. A. Brammall, Ph.D., M.Sc., F.G.S.
G. M. Davies, M.Sc., F.G.S.
Prof. W. G. Fearnsides, M.A., F.G.S.
Miss W. M. Porter, B.Sc.
A. F. Hallimond, M.A., F.G.S.
Dr. F. H. Hatch, O.B.E., Ph.D., F.G.S.
Sir Albert E. Kitson, C.M.G., C.B.E., F.G.S.
Prof. W. L. Bragg, O.B.E., M.A., F.R.S.

The elections of Prof. S. Kôzu, Prof. B. Mauritz, and Mr. H. M. Powell as Ordinary Members of the Society were confirmed.

The General Secretary then read the following

ANNUAL REPORT OF COUNCIL.

During the session 1929–30 four ordinary meetings have been held, by kind permission, in the apartments of the Geological Society, Burlington House, London, W.

Twelve papers have been read during the year, and at the March meeting Prof. W. L. Bragg delivered a lecture on 'The structure of silicates', in which he presented the results achieved by himself and his research students at Manchester.

Four numbers of the Journal of the Society (nos. 127–130) have been issued. They contain seventeen papers occupying 223 pages with ten plates, and 559 abstracts occupying 192 pages. The figures supplied by the Society's publishers show that the number of regular subscribers to the Journal is steadily increasing. The stock of the Journal has been re-arranged and re-counted, and is now stored in metal boxes and is much more readily accessible than formerly. The stock of some ten or more numbers is now very low, including three numbers issued as recently as 1928.

The balance-sheet for the year ending December 31, 1929, shows an excess of assets (exclusive of the Library and stock of the publications) over liabilities of £2,034 19*s.* 11*d.* The value of the stock invested in the names of the Trustees of the Society was on December 31, 1929, £1,713 17*s.* 0*d.* An examination of the accounts since the foundation of the Society in 1876 shows the stocks held to have cost, including brokers' charges, £1,976 9*s.* 5*d.* The depreciation shown is thus £362 12*s.* 5*d.*, or 13·28 per cent. on the purchase price, which, considering

the depreciation in value of trustee stocks in general during that period, is much less than might have been expected.

The Council regrets to announce the death of Mr. Samuel Henson on June 9, 1930; he was elected a member in 1879. Five Ordinary Members have resigned, and one has been removed from the List of Members in accordance with Bye-law 7. Thirteen new members have been elected, bringing the total membership on October 31 to 227, including eleven Honorary Members.

The Society's Library has received during the year 187 parts of periodicals and 19 reprints of papers. 32 volumes have been borrowed. The catalogue of separate copies of papers has been completed by the Librarian.

During the year the Society ceased to be a constituent member of the Federal Council of Chemistry. Mr. F. N. Ashcroft and Mr. W. Campbell Smith acted as the Society's delegates at the Centenary Celebrations of the Geological Society of France and presented an address. Dr. W. F. P. McLintock represented the Society at the International Congress of Mines, Metallurgy, and Applied Geology at Liége. Dr. G. F. Herbert Smith has continued to represent the Society on the Miscellaneous Minerals Committee of the Mineral Resources Department of the Imperial Institute.

On the motion of Lady McRobert, seconded by Dr. L. Hawkes, the report was adopted.

Captain G. M. Puckle proposed, and Dr. A. E. H. Tutton seconded, a vote of thanks to the Geological Society for the use of their rooms, which was carried unanimously.

Prof. W. T. Gordon exhibited a large crystal of emerald from Russia, and Mr. Francis Jones exhibited specimens of analcime and chabazite from Croft, Leicestershire.

The following papers were then read:—

1. An account of British mineral collectors and dealers in the seventeenth, eighteenth, and nineteenth centuries (Part I): by Mr. Arthur Russell.

2. Cupriferous melanterite from the Skouriotissa mine, Cyprus: by Mr. M. H. Hey (p. 413).

3. The dolerite-chalk contact-zone of Scawt Hill, Co. Antrim. The production of basic alkali-rocks by the assimilation of limestone by basaltic magma: by Dr. C. E. Tilley, with chemical analyses by Dr. H. F. Harwood (p. 439).

4. A simple method of observing the magnetic properties of mineral grains: by Dr. Frank Smithson (p. 419).

The following papers were taken as read:—

5. A contribution to the study of moonstone from Ceylon and other areas and of the stability-relations of the alkali-felspars: by Dr. Edmondson Spencer (p. 291). [*continued on p. lx.*]

MINERALOGICAL

ABSTRACT OF RECEIPTS AND PAYMENTS

Receipts.	£ s. d.	£ s. d.
		GENERAL PUR-
By Balances brought forward from 1929—		
1. At Bankers:		
(*a*) Deposit Account	170 0 0	
(*b*) Current Account (£10 3*s.* 8*d.*, less £1 14*s.* 2*d.* 'in trust for a member' transferred to Temporary Suspense Account)[1]	8 9 6	
2. In Office	0 9 9	
		178 19 3
Entrance Fees		10 10 0
Annual Subscriptions—		
1. Current year	152 2 11[2]	
2. Arrears	3 3 0	
3. Advance	5 5 0	
		160 10 11
Composition Fees		31 10 0
Sale of Publications—		
1. By Publishers, April 1, 1929–March 31, 1930. Subscription Payments £256 0*s.* 0*d.*, and other sales £49 13*s.* 6*d.*, less trade discount and commission £80 11*s.* 2*d.*, and distribution charges £14 16*s.* 10*d.*	210 5 6	
2. By Custodian of Stock, 1930. £8 12*s.* 9*d.*, less distribution charges £1 7*s.* 7*d.*	7 5 2	
		217 10 8
Advertisement Fees £34 18*s.* 4*d.*, less commission £6 19*s.* 8*d.*		27 18 8
Interest on Investments as received—		
1. £1,580 5% War Loan 1929–47 Inscribed Stock	79 0 0	
2. £105 4% Consolidated Loan 1957 Inscribed Stock	4 4 0	
3. £100 4% Funding Loan 1960–90 Inscribed Stock	3 0 0	
		86 4 0
Deposit Interest		3 13 7
Donation by Dr. E. Spencer (direct part payment for Illustrations)		8 13 6
Donation by F. N. Ashcroft (direct part payment for Metal Cases)		6 18 9
Small Receipts		0 2 11
		£732 12 3

[1] The item 'In trust for a member, £1 14*s.* 2*d.*', shown in the General Purposes Account and Balance Sheet for 1929, has been transferred to a Temporary Suspense Account (not published) to which certain moneys received and paid during 1930 have properly been credited and debited. The balance standing to the credit of this Account on December 31, 1930, was £6 11*s.* 9*d.*, and is taken into account in the Balance Sheet for the year ending on that day.

[2] Includes a part payment being balance due.

SOCIETY

FOR THE YEAR ENDING DECEMBER 31, 1930

POSES ACCOUNT.

Payments.	£ s. d.	£ s. d.
To Printing and distributing the Mineralogical Magazine Nos. 128–131 inclusive (Oxford University Press)—		
1. Printing	295 11 0	
2. Illustrations	54 15 0	
3. Authors' Separate Copies	28 18 3	
4. Distribution Charges	14 0 6	
		393 4 9
Printing and distributing notices of Meetings and other annual miscellaneous printing		17 6 3
Miscellaneous Printing, &c. (not annual)		0 19 0
Expenses at Meetings, 1930—		
1. Operator of lantern	2 2 0	
2. Porter	1 0 0	
3. Tea	2 10 0	
		5 12 0
Care of Stock of Publications—		
Annual fee, 1930, J. Mugford	1 1 0	
Metal Cases purchased	21 18 9	
Re-arrangement and re-count of stock, fee	2 10 0	
		25 9 9
Editor's Honorarium, 1930		50 0 0
Postage—		
1. Hon. Secretary	1 1 4	
2. Editor	1 4 10	
3. Hon. Treasurer (not charged)	—	
		2 6 2
Address to the Société Géologique de France		3 5 0
Stationery		5 12 0
Bank charges and other small items		0 1 2
Investments, purchase of £50 4% Funding Loan, 1960–90 Inscribed Stock, commission and stamp		45 4 3
Transferred to Library Fund Account		5 5 0
Balance, December 31, 1930—		
1. At Bankers:		
(*a*) Current Account	12 17 11	
(*b*) Deposit Account	165 0 0	
2. In Office	0 9 0	
		178 6 11
		£732 12 3

Examined and compared with vouchers and found correct.

F. A. BANNISTER
C. GILBERT CULLIS } Auditors.

January 8, 1931.

F. N. ASHCROFT, Hon. Treasurer.

LIBRARY FUND

Receipts.	£	s.	d.	£	s.	d.
By Balances brought forward from 1929—						
1. At Bankers	1	1	9			
2. In Office	0	1	10			
				1	3	7
Transferred from General Purposes Account				5	5	0
				£6	8	7

BALANCE

December

Liabilities.	£	s.	d.
By Cash in hand as per Temporary Suspense Account	6	11	9

Excess of Assets over Liabilities	2143	4	8
	£2149	16	5

ACCOUNT.

Payments.	£ s. d.	£ s. d.
To Librarian's Honorarium, 1930		5 0 0
Postage and other small items		0 6 1
Balance, December 31, 1930—		
1. At Bankers	1 1 9	
2. In Office	0 0 9	
		1 2 6
		£6 8 7

Examined and compared with vouchers and found correct.

F. A. BANNISTER
C. GILBERT CULLIS } Auditors.

January 8, 1931. F. N. ASHCROFT, Hon. Treasurer.

SHEET

31, 1930.

Assets.	£ s. d.	£ s. d.
To Balances—		
I. General Purposes Account:		
1. At Bankers:		
(*a*) Current Account	12 17 11	
(*b*) Deposit Account	165 0 0	
2. In Office	0 9 0	
		178 6 11
II. Library Fund Account—		
1. At Bankers: Current Account	1 1 9	
2. In Office	0 0 9	
		1 2 6
III. Temporary Suspense Account—		
At Bankers: Current Account		6 11 9
Sale of Publications—		
1. By Publishers, April 1 to Dec. 31, 1930	107 14 3	
2. By custodian	0 5 0	
		107 19 3
Advertisement Fees		29 8 6
Investments at Broker's Valuation—		
1. £1,580 5 % War Loan 1929–47 Inscribed Stock at 103	1627 8 0	
2. £105 4 % Consolidated Loan 1957 Inscribed Stock at 91½ ex div.	96 1 6	
3. £100 4 % Funding Loan 1960–90 Inscribed Stock at 94½	94 10 0	
		1817 19 6
Arrears of Annual Subscriptions, &c., valued at		8 8 0
		£2149 16 5

The value of the Library and that of the Stock of Publications are not included in the above assets.

January 17, 1931. F. N. ASHCROFT, Hon. Treasurer.

6. An electromagnetic separator for mineral powders: by Mr. A. F. Hallimond (p. 377).

7. On the orientation of kamacite in meteoric iron: by Mr. J. Young (p. 382).

8. Studies on the zeolites. Part I. General review: by Mr. M. H. Hey (p. 422).

THE MINERALOGICAL MAGAZINE
AND
JOURNAL OF
THE MINERALOGICAL SOCIETY

No. 132. March, 1931. Vol. XXII.

The dolerite-chalk contact of Scawt Hill, Co. Antrim. The production of basic alkali-rocks by the assimilation of limestone by basaltic magma.[1]

(With Plates XVII and XVIII.)

By C. E. Tilley, B.Sc., Ph.D., F.G.S.
Lecturer in Petrology, University of Cambridge,
and H. F. Harwood, M.Sc., Ph.D., A.I.C.
Lecturer in Chemistry, Imperial College of Science, London.

[Read November 4, 1930.]

Introduction.

In the following pages an account is given of the rock assemblages produced at the contact of a dolerite intrusion with chalk. Owing to the intense localized assimilation of calcium carbonate by the dolerite magma, unusual rock types are produced. The products of the endogenous contact-zone are dealt with in detail. Those of the exogenous contact-zone have in part been described already,[2] but some additional data are incorporated in this account. The study possesses more than local interest for two reasons: (*a*) The products

[1] Four of the new chemical analyses presented in this paper have been made by Dr. H. F. Harwood. Four other chemical analyses have been made in the Fresenius Chemical Laboratories, Wiesbaden. The field work and petrological investigations have been carried out by Dr. C. E. Tilley, who is also responsible for the writing of the paper.

[2] C. E. Tilley, Geol. Mag., 1928, vol. 65, p. 371; 1929, vol. 66, p. 347; 1930, vol. 67, p. 168 [Min. Abstr., vol. 4, pp. 84, 218, 330]. Min. Mag., 1929, vol. 22, p. 77; 1930, vol. 22, p. 222.

of the exogenous contact-zone are rare mineral assemblages; (*b*) In the endogenous contact-zone basic alkali-rocks are produced.

The extent to which foreign matter can be incorporated in liquid magma to produce new rock types is a much debated question in petrology. In particular, the nature and magnitude of the effects following incorporation of carbonate sediment are still highly controversial. Limestones and alkali-rocks are not infrequently closely associated, but in most of the examples previously described in support of a genetic relation between the two rock types there has been little decisive evidence that the magma was not already rich in alkalis before this association came about. In particular, the supposed process of generation of the alkali-rock has not been substantiated by tracing the development of this rock through intermediate stages by field, chemical, and microscopical data. The nature of the supposed reactions has therefore been largely hypothetical.

It is believed that the occurrence now described is unique, inasmuch as the successive stages resulting in an alkali-rich residual magma can be followed in a narrow zone at the contact of limestone and dolerite. It will be shown that the reactions ultimately giving rise to the alkali-rocks are complex. They are essentially different from those hypothesized by the petrologists who have given consideration to this question in the past.

Field Occurrence.

Scawt Hill, situated six miles north of Larne, Co. Antrim, forms a prominent height rising to 1,249 feet on the eastern edge of the Antrim 'plateau basalt' lavas. The geological structure of this portion of Antrim is comparatively simple. A denuded platform of chalk and older Mesozoic rocks is covered by the Antrim Tertiary basalts, which are divisible into a lower and upper series, separated by a well-defined horizon of bauxitic and pisolitic iron-ore deposits. Scawt Hill itself forms a mass of olivine-dolerite breaking through the chalk and lower basalt series, and as now exposed by denudation forms a small boss, flanked on the west by basalt and by chalk on the east, where it forms a precipitous cliff, 100–200 feet high. The contact with the chalk is well exposed on the SE. side, and this outcrop extends as a thin veneer northward on the steep slope of the hill, where the actual contact may be studied in detail (fig. 1). Still farther north a small mass of chalk in contact with the dolerite

displays on the hillside an almost vertical junction, which can be traced up the slope (fig. 2). This exposure provides an excellent section of the contact relations of the two rocks. A little to the east the chalk is cut off by a fault, which lets down basalt against it. On the slope below the SE. contact, the screes provide many blocks of the highly metamorphosed and metasomatized chalk, as well as of the dolerite and the hybrid rock at the immediate contact.

Fig. 1. Scawt Hill, Co. Antrim, viewed from the east. The vertical junction of the chalk and dolerite is well seen in the contact on the right.

The steep, almost vertical, slope above the chalk contact on the south-eastern side must represent the actual junction for some yards vertically, for isolated patches of silicated chalk, forming a thin skin to the dolerite, can be followed above the continuous chalk outcrop. The dolerite intrusion forms a boss of approximately 300 × 200 yards dimensions, and the visible line of exposure along the chalk margin is about 70 yards, while a vertical section of 50 feet or more is provided in the isolated mass of chalk of the northern exposure. The unaltered chalk away from the contact is a white compact rock with abundant flint nodules. Otherwise it is a pure carbonate-rock without detrital materials. Approaching the contact it becomes recrystallized to a coarse marble, which within a few feet passes into a tough silicate assemblage, varying in colour and texture according to the nature of the minerals dominantly produced.

The dolerite is a typical fine-grained olivine-bearing type, preserving a very uniform composition through its extent, except in the

immediate vicinity of the chalk. Here within a few feet it rapidly changes its texture and composition: it becomes coarser grained, often strongly vesiculated, and variable in composition from point to point. However irregular the junction between the modified

Fig. 2. Northern contact of chalk and dolerite, Scawt Hill.

dolerite and altered chalk may be, the line of contact is always a sharp one. This modified dolerite zone, although at the most only a few feet wide, is clearly a hybrid one, as the nature of its mineral assemblages attests. It will be referred to hereafter as the endogenous contact-zone.

The Exogenous Contact-zone.

The zone of silicates at the immediate contact with the intrusion is of variable width. At the northern contact the width is only a few inches and the rock consists principally of a dense-grained larnite type. At the southern contact the silicate zone is wider and more varied in its constitution. It probably nowhere exceeds two feet in width, and may be much less. This silicate zone passes out into a coarse marble for a few inches and then grades into the

normal chalk with its flint nodules. The latter in the silicate zone often retain their identity, but are usually separated from the normal silicate zone by a narrow sheath of wollastonite. Not only the width but also the nature of the silicate zone varies from place to place. At one point the chief product may be a spurrite-rock, at another a larnite assemblage or a more complex aggregate. These rock types may be subdivided as follows:

Spurrite-rock (with or without calcite).
Larnite-rock (with or without spurrite).
Spurrite-larnite-gehlenite-rock.
Spurrite-gehlenite-merwinite-spinel-rock (with or without larnite).

If calcite be present in any of these assemblages it is not found in direct contact with larnite, which in its vicinity gives place to spurrite:

$$\underset{\text{(larnite)}}{2Ca_2SiO_4} + CaCO_3 \longrightarrow \underset{\text{(spurrite)}}{2Ca_2SiO_4.CaCO_3}.$$

A detailed mineralogical account of these assemblages has already been published,[1] but some further mineral data are now available and are included here. The following is a list of the minerals recorded from the exogenous contact-zone:

Calcite, Chalcedony } Chalk	Magnetite
Spurrite	Perovskite
Larnite (α and γ)	Wollastonite
Merwinite	Xonotlite
Gehlenite	Gyrolite
Spinel	Afwillite
	Ettringite

Perovskite.—In many of the contact assemblages perovskite is present as minute coloured octahedra or grains which do not show any sign of birefringence. These grains are very sporadic in their distribution. Occasionally at the immediate contact the grains reach larger dimensions, and are then noticeably birefringent as they uniformly are in the hybrid rocks. The source of this titanium is without doubt the olivine-dolerite.

Wollastonite.—This mineral is not a normal constituent of the exogenous contact-zone. The presence of flint nodules in the chalk, however, is responsible for its occurrence, inasmuch as silica in excess is available for its production. Flint nodules in the contact-zone retain their identity as such, and are enveloped by spurrite-

[1] C. E. Tilley, Min. Mag., 1929, vol. 22, pp. 77–86.

larnite assemblages. At the junction the spurrite and larnite give place to a narrow fringe of wollastonite, and this mineral also forms small veins through the nodules themselves, where lime-rich solutions have penetrated the flint. In some examples the chalcedony of the flint has recrystallized near the edge to a coarser aggregate of quartz, and here this outer zone gives place to an assemblage consisting of xonotlite and wollastonite.

Xonotlite.—This mineral forms aggregates of fibrous radiating crystals enclosing comparatively large blades of wollastonite up to 3 mm. in length. The optical properties of these fibrous aggregates are sufficiently distinctive to indicate that they are xonotlite ($5\,CaSiO_3.H_2O$): α 1·578, γ 1·590, elongation positive, 2V small or nearly uniaxial. This occurrence of xonotlite resembles in some respects its occurrence at Leesburg, Virginia, where Shannon[1] has described xonotlite as radiating masses filled with pearly wollastonite of fine-bladed structure among the contact products of dolerite and Triassic limestone.

Afwillite.—The occurrence of this mineral has already been recorded,[2] and in association with it is found ettringite. An account of this rare mineral is deferred.

Gyrolite.—Like afwillite and ettringite, this mineral occurs in cavities in a crust to a spurrite contact-rock, and it is as clearly of secondary origin. It appears as flat plates up to one millimetre across and possesses a perfect basal cleavage. Optical examination shows that it is in part uniaxial and in part biaxial, the uniaxial part forming a zone wholly or partly surrounding a biaxial centre. The refraction is ω 1·59, birefringence negative, density 2·3. The mineral appears to be one of the degradation products of spurrite.

Discussion.—The mineral assemblages of the contact-zone bear witness to the intense metasomatism which has locally affected the limestone. The purity of the chalk—apart from the flint nodules—outside the silicate zone clearly denotes that solutions from the dolerite magma enriched the contact-zone in many of its constituents. The migration of silica is attested in the abundant spurrite and larnite assemblages, but a more complex metasomatism is indicated in the assemblages bearing gehlenite, merwinite, spinel, and perovskite. To study in more detail the nature of this metasomatism an

[1] E. V. Shannon, Proc. U.S. Nat. Museum, 1925, vol. 66, art. 28, p. 11. [Min. Abstr., vol. 3, p. 204.]

[2] C. E. Tilley, Geol. Mag., 1930, vol. 67, pp. 168–169.

analysis of a spurrite-gehlenite-merwinite-spinel-rock has been made. The mineral composition of the rock in weight percentages is spurrite 51, spinel 18, merwinite and gehlenite 30. The analysis is given in the accompanying table (column 1). The composition is seen to correspond closely to a mixture of 100 parts of the analysed olivine-dolerite plus 72 parts CaO (column 3). It would appear, therefore, that in this and similar assemblages there has been an infiltration of olivine-dolerite magma with little, if any, selective diffusion.

	(1)	(2)		(3)	
SiO_2	22·52	23·70		27·7	
Al_2O_3	10·11	10·64		9·4	
Fe_2O_3	4·58	4·82	7·87	1·4	6·3
FeO	2·90	3·05		4·9	
MgO	4·93	5·19		5·0	
CaO	46·36	48·80		48·8	
Na_2O	1·06	1·12		1·3	
K_2O	0·05	0·05		0·2	
H_2O-	0·08	0·09		0·6	
H_2O+	0·78	0·80			
CO_2	5·08	—		—	
TiO_2	0·57	0·60		0·6	
P_2O_5	0·19	0·20		0·1	
SO_3	0·49	0·51		—	
FeS	0·18	0·19		—	
	99·88	99·76		100·0	

(1) Spurrite-merwinite-gehlenite-spinel-(calcite)-rock. (Analyst, Fresenius Chemical Laboratories, Wiesbaden.)

(2) Analysis (1) recalculated to zero CO_2.

(3) Mixture of 100 parts Scawt Hill olivine-dolerite plus 72 parts CaO (corrected to 100%).

There are other assemblages where there is reason to believe that igneous solutions of different composition have penetrated the chalk, but the effects there noted are more localized, confined to lenses and veins, and therefore more appropriately described in the section dealing with the changes produced in the endogenous contact-zone (p. 463).

The Scawt Hill contact-zone is unique in its mineralogy. Elsewhere assemblages of this bulk composition are mineralogically represented by wollastonite-calcite in place of larnite-spurrite, while the more complex spurrite-larnite-merwinite-melilite(gehlenite)-spinel association would be represented by wollastonite-diopside-grossular-(idocrase)-calcite assemblages. Wollastonite here is produced only in contact with silica, as around flint nodules. In the

reversible equilibrium $CaSiO_3 + CaCO_3 \rightleftarrows Ca_2SiO_4 + CO_2$, the right side of the equation at low pressures represents the stable assemblage at high temperatures, but we note further that the orthosilicate in the presence of calcite gives place to the double compound, spurrite. Spurrite has not yet been synthesized, but an orthorhombic spurrite (α-spurrite) has been produced by Shepherd [1] and Eitel,[2] the former by heating $CaCO_3$ and Ca_2SiO_4 with 10 % NaCl solution at temperatures of 350–400° C., the latter from a melt at 120 atmospheres CO_2 pressure. According to Eitel, α-spurrite melts incongruently with separation of β-Ca_2SiO_4 at 1380° C., while natural spurrite heated under pressure inverts to the orthorhombic form at 1200° C. The reverse transformation has not been effected. Merwinite is not recorded from dry melts at all, but is represented by mixtures of monticellite and Ca_2SiO_4.

This unusual character of the Scawt Hill assemblages is probably due to the high temperature prevailing during metamorphism. In this process the solutions emanating from the magma played a necessary part, modifying the composition and effecting a rapid rise in temperature in the limestone, apart from conduction. The occurrence of larnite (α-Ca_2SiO_4), which is strictly stable only above 1420° C., cannot, however, be used as a geologic thermometer, for it is well known that high-temperature forms may be directly formed at temperatures below their real stability range. This contact-zone is, however, perhaps the most striking example of a rock body largely built up of a mineral in unstable equilibrium. The reason for its preservation is probably to be sought in a comparatively rapid rate of cooling, whereby reactions among the minerals have been practically inhibited.

The Endogenous Contact-zone.

The minerals of the endogenous contact-zone may be conveniently tabulated together:

Augite	Dolerite	Anorthoclase
Labradorite		Nepheline
Olivine		Magnetite
Magnetite		Ilmenite
[Serpentine, chlorite]		Pyrite
Apatite		Pyrrhotine
Titanaugite		Calcite

[1] F. E. Wright, Amer. Journ. Sci., 1908, ser. 4, vol. 26, p. 551.
[2] W. Eitel, Neues Jahrb. Min., 1923, Beil.-Bd. 48, p. 63.

Soda-augite	Thomsonite
Aegirine	Analcime
Hastingsite	Natrolite
Melilite	Hydronephelite
Wollastonite	Stilbite
Fayalite	Cebollite
Perovskite	Scawtite
Sphene	Grossular

The rocks of this zone comprise a varying group of assemblages, which may be classified as follows :

Olivine-dolerite (p. 447).
Pyroxene-rich dolerites (p. 449).
Pyroxenites (p. 449).

Titanaugite-rocks (p. 451) :

(*a*) Titanaugite-plagioclase
(*b*) Titanaugite-plagioclase-nepheline
(*c*) Titanaugite-nepheline(hydronephelite)
} assemblages.

Titanaugite-melilite-rocks (p. 454) :

(*a*) Plagioclase-bearing types, with nepheline.
(*b*) Plagioclase-free types, with nepheline (often converted to thomsonite) and wollastonite.

Melilite-rocks, wanting in titanaugite, but carrying perovskite, wollastonite, and interstitial aegirine (p. 457).

Some of these rock types have been analysed, and for convenient reference and comparison the analyses have been collected together in the table overleaf (p. 448).

Olivine-dolerite.

The chief rock of the intrusion is a normal olivine-dolerite (pl. XVII, fig. 1), like many of the dolerites of the Hebridean ' plateau magma basalt ' type. It is a non-porphyritic type with ophitic to subophitic texture and is typically fine-grained. The primary constituents are olivine, augite, plagioclase, iron-ores, and accessory apatite. Secondary minerals are very subordinate, and include serpentine and fine scaly chlorite. The plagioclase, which is the dominant mineral, forms about 50 % of the rock. Its composition is, approximately, $Ab_{35}An_{65}$ ($\alpha' : (010) = 35°$, γ 1·571). The pyroxene, with which it is ophitically intergrown, is a colourless to grey-brown variety with α 1·69, γ 1·71, $\gamma : c = 45°$, optically positive. The olivine, which is of early crystallization, being frequently mantled by the pyroxene, is an optically negative type and quite colourless. It has suffered some serpentinization. The iron-ores have the habit and

	(1)	(2)	(3)	(4)	(5)	(6)
SiO_2	47·55	46·77	42·24	37·54	29·14	22·52
Al_2O_3	16·18	14·93	13·16	13·39	10·46	10·11
Fe_2O_3	2·46	2·20	4·48	3·60	8·54	4·58
FeO	8·35	5·65	12·61	11·95	7·85	2·90
MgO	8·62	7·87	1·66	2·36	1·06	4·93
CaO	11·86	17·87	13·66	21·25	28·40	46·36
Na_2O	2·19	1·50	3·84	1·50	2·18	1·06
K_2O	0·35	0·29	0·78	0·38	0·19	0·05
H_2O-	0·42	0·24	0·48	0·05	0·41	0·08
H_2O+	0·80	1·72	4·48	5·71	5·17	0·78
CO_2	0·03	0·16	0·12	0·20	3·02	5·08
TiO_2	1·11	1·06	1·81	2·04	2·17	0·57
P_2O_5	0·14	0·28	0·60	0·64	0·68	0·19
MnO	0·16	0·09	0·30	—	0·34	—
BaO	0·02	trace	0·06	—	0·07	—
S	trace	0·02	0·21	—	0·30	0·49 (SO_3)
Cl	—	—	—	—	0·06	0·18 (FeS)
F	—	—	—	—	0·02	—
V_2O_3	—	—	—	—	0·03	—
NiO	—	trace	—	—	—	—
	100·24	100·65	100·49	100·61	100·09	99·88
Fe/Mg	1·6	1·25	13·0	8·3	19·0	1·8

(1) Olivine-dolerite, Scawt Hill. (Analyst, H. F. Harwood) (p. 447).

(2) Pyroxene-rich dolerite. (Analyst, H. F. Harwood) (p. 450).

(3) Nepheline(hydronephelite)-dolerite. (Analyst, H. F. Harwood) (p. 452).

(4) Titanaugite-melilite hybrid rock or melilite-bearing nepheline-dolerite. (Analyst, Fresenius Chemical Laboratories, Wiesbaden) (p. 456).

(5) Melilite-rock (hybrid zone). (Analyst, H. F. Harwood) (p. 459).

(6) Spurrite-merwinite-gehlenite-spinel-(calcite)-rock (metasomatized chalk). (Analyst, Fresenius Chemical Laboratories, Wiesbaden) (p. 445).

The normative compositions of these rocks are as follows:[1]

	(1)	(2)	(3)	(4)	(5)
Orthoclase ...	2·2	1·6	4·5	—	—
Albite	18·3	8·5	11·3	—	—
Nepheline	—	2·2	11·5	8·6	10·5
Anorthite	33·4	33·1	16·4	30·3	18·2
Diopside	20·0	42·4	40·1	36·6	13·9
Hypersthene ...	7·1	—	—	—	—
Olivine	11·9	4·4	—	3·0	—
Wollastonite ...	—	—	0·3	—	2·6
Larnite	—	—	—	10·3	23·7
Magnetite	3·5	3·2	6·5	5·5	12·4
Ilmenite	2·1	2·0	3·4	4·1	4·1
Apatite	0·3	0·6	1·4	1·6	1·4
Calcite	—	—	—	—	6·9
Water	1·2	1·9	4·9	—	5·6

[1] Such K_2O as is not incorporated in normative orthoclase is here computed

character of magnetite and are magnetic, but must contain the bulk of the titanium. They have crystallized in part later than the plagioclase.

The dolerite retains these characters to within a few yards of the chalk contact. The analysis of the rock and the norm have been given in the preceding table (p. 448). A micrometric estimation of the minerals present in this rock shows that the mode does not differ greatly from the norm. The olivine constitutes about 11 % by weight. The optical properties of the felspar indicate a composition almost identical with that of the plagioclase of the norm (An 65 %, total felspar 53·9 %), indicating that the alumina percentage of the pyroxene cannot be appreciable. The hypersthene of the norm does not, of course, occur as such in the mode, but is present in solid solution in the monoclinic pyroxene.

Pyroxene-rich Dolerites and Pyroxenites.

Among the products in the endogenous contact-zone the types now to be described are the most abundant. The olivine-dolerite merges within a few feet of the contact into a rock rich in pyroxene. This is typically coarser grained than the dolerite itself, and a distinctive feature is its vesicular nature. The rocks classed under this head are grey-black in colour, very rich in pyroxene, often to the exclusion of visible felspar. The grain-size of the majority averages round 1½–2 mm., but examples occur locally where the individual pyroxenes may reach 5–6 mm., or even more, in diameter. In their section the dominant pyroxene is a grey to grey-brown variety, not infrequently zoned, with the outer shell more strongly coloured. Olivine is always very subordinate and in many examples is altogether absent. Felspar is typically reduced to an interstitial constituent. In the pyroxenite proper it is completely absent. The vesicles which characterize the rock are filled with zeolites, of which thomsonite is the chief, but analcime, stilbite, and natrolite are also recorded, as well as calcite.

Thomsonite and analcime are present not only in the vesicles, but also form a residual base in places, though never large in amount. It is clear that the interstitial plagioclase has been attacked and is often replaced by thomsonite or even analcime. In one example hydronephelite replaces the plagioclase-felspar. One of the less

as kaliophilite, instead of leucite, and added to nepheline. No. 4 is calculated water-free.

extreme types of these rocks has been analysed. It comes from the immediate contact with the altered chalk at the southern exposure. Thin sections of the rock show it to be somewhat variable in its mineral composition from point to point. At one place plagioclase may be seen in ophitic intergrowth with pyroxene, while in adjacent parts of the slides the rock locally becomes a pure pyroxenite.

In its richness in pyroxene, paucity in olivine (not more than 3 %), and in its vesicular character, this rock differs very markedly from the associated dolerite. The pyroxene has much the appearance of the pyroxene of the dolerite with α 1·69 and the highest value for γ 1·72. Iron-ores are, as before, magnetite. The plagioclase is an optically positive labradorite of similar composition to that in the dolerite already described (Ab_{35}), and the vesicle minerals are thomsonite and subordinate analcime. The analysis of this rock is given on p. 448. Owing to the presence of considerable thomsonite, the mode and norm are now not directly comparable, as they were in the olivine-dolerite. Apart from the modal representation of some normative anorthite as thomsonite, the pyroxene is somewhat aluminous (see below), and thus the normative plagioclase is considerably more calcic than the modal plagioclase.

An analysis of a pyroxene isolated from a true pyroxenite is given below. The rock is a pyroxenite, with only a few scattered grains of olivine and containing only very minor amounts of plagioclase as an interstitial base (pl. XVII, fig. 2). Thomsonite and a little analcime are present, chiefly in vesicles, but thomsonite is also developing from the plagioclase. The rock may be taken as the extreme type to which the pyroxene-rich dolerites graduate. It is noteworthy that iron-ores are very scanty. The pyroxene is greenish in crushed fragments, but in thin sections greyish, except in narrow outer shells to some of the grains, where it may be tinted a green-brown colour. Immersion gave the refraction as extremes α 1·698 and γ 1·730; $\gamma : c = 43°$. The analysis expressed in the usual components shows that the mineral is essentially a diopside-hedenbergite, with 90 % of these molecules, while hypersthene is only 2·3 %. As the iron and magnesium of the pyroxenite are practically wholly contained in the pyroxene, the Fe/Mg ratio of the mineral is practically that of the rock Fe/Mg = 0·71, compared to Fe/Mg for the olivine-dolerite 1·6. The precipitated pyroxene is enriched in diopside molecules (Di 72·8, Hd 17·4). It is noteworthy also that the pyroxene contains significant alumina. We shall see that in the

pyroxenes generated by further lime assimilation, this oxide figures to a much larger extent in the pyroxenic constitution.

			Molecular composition.		
SiO_2	...	49·31			
TiO_2	...	1·26	Diopside	72·79	90·22
Al_2O_3	...	4·60	Hedenbergite ...	17·43	
Fe_2O_3	...	2·38	$(Fe,Mg)SiO_3$	2·35	
FeO	...	5·57	Al_2O_3	4·60	
MgO	...	14·02	Fe_2O_3	2·38	
CaO	...	22·71	SiO_2 (excess) ...	0·30	
		99·85		99·85	
Fe/Mg	...	0·71			

Pyroxene from pyroxenite, Scawt Hill. (Analyst, Fresenius Chemical Laboratories, Wiesbaden.)

Titanaugite-rocks.

The rocks (figs. 3, 7, and 8) now to be described are distinguished both from the dolerite and pyroxenites by the nature of the essential pyroxene. They are rich in a strongly-coloured pyroxene, recognizable in the field and in hand-specimens by its lustrous black colour, and in thin section appearing in varied shades of brown, green-brown passing into red-brown, and purplish tints, thus denoting a significant titanium content. The rocks are typically medium to coarse grained, the average grain-size being 2–3 mm., but in extreme examples the augites may reach an inch in length. These assemblages are restricted to the endogenous contact-zone and are found in close association with the pyroxenites, passing out into them and occurring in segregatory patches and even in small veins through the dolerite on the edge of the contact-zone. Mineralogically they may be grouped into (*a*) Augite-plagioclase-rocks, (*b*) Augite-plagioclase-nepheline-rocks, and (*c*) Augite-nepheline-rocks. Collectively they represent an important stage in the differentiation process in the endogenous contact-zone and are the complement of the pyroxenites, originating from the dolerite magma by enrichment in Na_2O and FeO by segregation of these constituents during the formation of the pyroxenites. This enrichment has been accompanied by a further lime assimilation.

In some of the pyroxenites, the beginning of the process of iron enrichment of the residual liquid is indicated by the outgrowth of a narrow brown zone to the light-coloured pyroxene, where this is bordered by the residual liquid, now in part represented by zeolitic material. This process culminates in a liquid which gives rise to the rock types now described. The dominant type is a red-brown-

augite-plagioclase-rock with some magnetite. Analcime is a typical accessory, both interstitially and as a common product replacing the plagioclase. The augites are zoned, sometimes with hour-glass structure, elongated parallel to the *c*-axis and flattened parallel to (100). The zoning is such that a brown core passes into a red-brown periphery, which is itself sometimes fringed with a green or brown-green edge. The plagioclase is an optically positive labradorite (An_{50}–An_{55}) and is in places in process of replacement by analcime or thomsonite or both. The entry of nepheline in these rocks is at the expense of the plagioclase, which is resorbed, giving ragged irregular grains mantled by nepheline. Graphic intergrowths between pyroxene and nepheline (or, as now seen, its alteration product, hydronephelite) now begin to appear. It is noteworthy that intergrowths of this kind never occur between pyroxene and plagioclase. With increase in nepheline the large pyroxenes now assume more constantly a purplish tint, though the graphically intergrown pyroxene is a greener or brown-green type. The pyroxene of these intergrowths may form separately or spring from the boundaries of large titanaugites.

The ultimate product is a pyroxene-rich nepheline-dolerite with acicular purple augites up to half an inch in length, with the optical properties a 1·73, γ 1·75, $\gamma : c = 55°$, pleochroism γ yellowish-brown, β ruddy-brown, α reddish-brown with violet tint. A narrow fringe of aegirine-augite is not uncommon. The nepheline shows well its habit of hexagonal prisms, giving rectangular and hexagonal sections, but it is in large part converted to fibrous masses of hydronephelite—uniaxial positive, elongation positive (ω 1·490, ϵ 1·500). Thomsonite is also produced, though in minor amount (fig. 9). The development of hydronephelite from nepheline can be followed in every stage, beginning at the periphery and spreading along the prismatic cleavages. The masses of fibres preserve, however, no common orientation. Some yellow fayalite is typically present: it is partially or wholly altered into a brown serpentine and magnetite. Apatite and magnetite are accessory. The production of such a rock type can be very clearly seen where an augite-plagioclase type borders the altered chalk; plagioclase becomes strongly resorbed, mantled by nepheline until eventually in areas all the plagioclase disappears and a pyroxene-rich nepheline-rock arises. The probable reactions by which this process is completed will be discussed hereafter. The analysis of the rock type just described is given on p. 448 (column 3).

This nepheline-dolerite analysis corresponds closely to those of nepheline-basalts, the chief distinction being the exceptionally low value for MgO. It may also be compared with analyses of bekinkinites and fasinites, e.g. those described by Lacroix[1] from Madagascar. The latter rocks, which are closely related to the theralites, are distinguished from the ijolites by the presence of a titanaugite instead of an aegirine-diopside. The fasinite of Ambaliha, Madagascar, is rich in titanaugite of the composition SiO_2 46·60, Al_2O_3 6·07, Fe_2O_3 4·85, FeO 3·72, MgO 12·21, CaO 23·88, Na_2O 0·47, K_2O 0·28, TiO_2 1·59, H_2O 0·26. It is thus an aluminous type with excess CaO expressed as $CaSiO_3$ in the molecular composition, or as the Wahl[2] silicate, $CaAl_2SiO_6$. This analysis is of the same general type as that of the pyroxene from the titanaugite-rocks of Scawt Hill, and it is to be noted that in both cases the alkalis are insignificant in amount.

Anorthoclase-fayalite-dolerite.—An unusual assemblage containing anorthoclase occurs in an inch-wide segregation vein in the dolerite near the edge of the hybrid zone. Brown augite and labradorite are the chief constituents, but there is also present anorthoclase, fayalite-olivine, magnetite, apatite, thomsonite, and small amounts of an alkali-amphibole. The brown augite has in places fringes of a green soda-augite. The anorthoclase occurs as shells mantling cores of labradorite, but also forms independent crystals of late crystallization. It is distinguished by its exceedingly fine multiple twinning, comparatively low optical axial angle, extinction, and negative sign. With it is associated fayalite in much the same way as this latter mineral is associated with nepheline in the nepheline-dolerites.

The alkali-amphibole accompanies the fayalite, often forming small crystals around its borders. These crystals are greenish to bluish-green, but may have a brown core. The pleochroism is very striking and the dispersion very strong: α yellow-green, β green, γ plum-blue; $\beta : c = 30°$, $\gamma = b$. The transverse position of the optic axial plane ($\perp$ 010) and the very small optic axial angle, together with the properties mentioned above, show that this amphibole belongs to the hastingsite group. This occurrence is the only record of alkali-amphibole among the Scawt Hill rocks. The rock, with its strongly-coloured augite, is clearly a relative of the augite-dolerites, and the presence of fayalite and anorthoclase indicates the

[1] A. Lacroix, Min. Madagascar, 1922, vol. 2, pp. 639, 645.

[2] W. Wahl, Tschermak's Min. Petr. Mitt., 1907, vol. 26, p. 118.

soda and iron enrichment. It seems probable that it is the siliceous representative of the augite-plagioclase-nepheline types, anorthoclase appearing in place of nepheline.

Titanaugite-melilite-rocks.

With the exception of the melilite-rocks themselves, the rocks (figs. 4, 5, 6, 9, 10, 11) described under this head are the coarsest of all the assemblages found in the endogenous contact-zone. They occur at the immediate contact with the altered chalk, and have a somewhat variable composition. The chief constituents are titan-augite, melilite, plagioclase, nepheline, wollastonite, and often much thomsonite in vesicles or replacing plagioclase or nepheline. In addition, a green pyroxene is frequently present as feathery growths in the groundmass around the melilite or titanaugite. The rocks may be divided into (*a*) plagioclase types and (*b*) plagioclase-free types. These rocks seem clearly to be derived from the augite-plagioclase- and augite-plagioclase-nepheline-rocks, already described, under the influence of further lime assimilated at the contact. The chief mineralogical features of these rocks will now be discussed.

Titanaugite.—This mineral forms large crystals up to an inch or more in length and has the same habit as the titanaugite of the titanaugite-nepheline-dolerite. The optical properties are also closely similar and distinguished by even higher values of the refractive indices, α 1·74, γ 1·76. The pleochroism is, as before, α red-brown with a violet tint, β red-brown, γ yellow-brown. Hour-glass structure is common and dispersion $\rho > v$ very noticeable for optic axis *B*. The pyroxene of a typical coarse-grained variety, free from plagioclase, but with much of its nepheline replaced by thomsonite, and also bearing wollastonite, was isolated and analysed, with the following results :

SiO_2	...	40·28			
TiO_2	...	3·85	Molecular composition.		
Al_2O_3	...	10·30	Diopside ...	...	42·01
Fe_2O_3	...	5·35	Hedenbergite	...	28·24
FeO	...	7·92	Aegirine ...	...	2·67
MgO	...	7·78	Wollastonite	...	10·11
CaO	...	23·57	Al_2O_3 ...	...	10·30
Na_2O	...	0·36	Fe_2O_3 ...	...	4·43
K_2O	...	trace	CaO (excess)	...	1·63
H_2O	...	0·19			
		99·60			99·39

Titanaugite, from melilite-nepheline-dolerite, Scawt Hill. (Analyst, Fresenius Chemical Laboratories, Wiesbaden.) Sp. gr. 3·391.

This augite is thus both a lime-rich type and at the same time highly aluminous. Its molecular composition indicates over 10 % wollastonite, otherwise expressed as 19 % of the Wahl silicate ($CaAl_2SiO_6$). In the calculated norm, alumina would appear as anorthite (26·46 %) and the excess lime as larnite (11·24 %). Such lime-rich and alumina-rich augites are not uncommon in basic alkali-rocks bearing nepheline and leucite. One example has already been quoted, viz. the augite of the Madagascar fasinite referred to in the description of the nepheline-dolerite. H. S. Washington [1] has recently shown that the augites of the basic leucite-rocks of the Alban Hills are also lime- and alumina-rich types, showing 9–10 % of $CaSiO_3$ in their molecular composition. At the same time, despite the high content of alkalis in the magma, the augites themselves are not of alkali types (cf. the lime-rich augite from the Fosso del Tavolato with CaO 24·50, Na_2O 0·46, K_2O nil). The titan-lime-augite of Scawt Hill is of very different composition from the augite of the olivine-dolerite, with its excess of the hypersthene molecule. At Scawt Hill these complex lime-pyroxenes have played a notable part in the differentiation process in the endogenous contact-zone.

Melilite.—In these rocks melilite forms large crystals up to an inch in diameter, associated with titanaugite, nepheline, and wollastonite. Its physical and optical properties are essentially similar to those of the melilite of the melilite-rocks (p. 457). As seen in these rocks, the melilite is very susceptible to alteration, and in some of them all of it has been destroyed. Quite commonly, however, residues of melilite are found reposing in a mass of alteration products. The chief of these is the mineral cebollite, but calcite and scawtite also figure as degradation products.

Cebollite, $Ca_5[Al(OH)_2]_2(SiO_4)_3$, first appears as fine brownish fibres developing along the cleavages and cracks in the melilite, the fibres standing perpendicular to the cleavage cracks. Ultimately, by an extension of this process, the whole of the melilite may be converted to a mass of cebollite fibres. At the same time the cebollite may be accompanied by a separation of finely-divided magnetite, which is subsequently hydrated to a brown or yellowish iron hydroxide. The cebollite resembles in all respects that described by Larsen [2] from

[1] H. S. Washington and H. E. Merwin, Amer. Min., 1923, vol. 8, p. 104. [Min. Abstr., vol. 2, p. 305.]

[2] E. S. Larsen and W. T. Schaller, Journ. Washington Acad. Sci., 1914, vol. 4, p. 480.

the melilite-rocks of Gunnison Co., Colorado. The fibres have a refraction of 1·61, straight extinction, and positive elongation, with a moderate double refraction (fig. 12).

Plagioclase.—Labradorite in these rocks varies much in amount. In some it is abundant, in others altogether absent. Its place is partly taken by nepheline, which is repeatedly seen in process of development at its expense, resorbed grains of labradorite being mantled by nepheline. A later change, namely conversion of the labradorite to thomsonite, is also important, and the same process also affects the nepheline. Thomsonite, indeed, is by far the commonest zeolite mineral in the endogenous contact-zone. Its distinctive optical properties—biaxial, optically positive, axial plane across the fibres, hence elongation β, refraction 1·52–1·53, birefringence 0·012—distinguish it from other zeolites. Hydronephelite, on the other hand, is distinctly uncommon in this group of rocks.

Wollastonite is present in the plagioclase-free variety of these rocks, and it is typically developed in the ground between the melilite and titanaugite, often springing from the borders of the melilite crystals and forming part of a thomsonitic base derived from the alteration of nepheline. It forms finger-like growths in this way and may be intimately associated with the feathery green pyroxene, which also constitutes a portion of the base. This green pyroxene first appears as outgrowths from the titanaugite, and then as feathery growths in the zeolitic matrix. It is a green soda-augite of high extinction-angle and is clearly a late crystallization. It comes, in part at least, from melilite and titanaugite, at a late stage developing from their resorbed borders as a felt of thin fibres.

An analysis of such a plagioclase-free titanaugite-melilite-rock is given on p. 448. The constituents are titanaugite, nepheline, in large part replaced by thomsonite, wollastonite, melilite, fibrous green pyroxene, calcite, iron-ore (magnetite), and apatite. As might be expected, the lime is very high (21·25 %) and MgO low (2·36 %). The low value of soda (1·50 %) is due to the replacement of much of the nepheline by thomsonite. In common with the nepheline-dolerite analysis, the Fe/Mg ratio is much higher than in the case either of the olivine-dolerite or the pyroxenite. This point will be further dealt with in treating of the genesis of the rock types. The abnormal character of the analysis is shown in the calculated norm, which carries 10·3 % of larnite. Five thin sections of this analysed rock were cut, owing to the coarse grain-size and variable distribution of

the minerals. Nepheline, altered in large part to thomsonite, and titanaugite are the most abundant constituents. Melilite is very variable, and does not at most exceed 10 %. The rock is best referred to as a melilite-bearing nepheline-dolerite.

Melilite-rocks.

Assemblages (fig. 12) grouped under this head have a much more limited development than any of the preceding types. They occur in intimate association with the metasomatized chalk, in irregular pockets, lenses, and veins, but always with sharp if irregular junctions with that rock. Their mode of occurrence, texture, and composition indicate their origin as extreme hybrids between magmatic solutions and limestone, and not as metasomatic replacements. As seen in hand-specimens, they are coarse-grained aggregates built up of honey-yellow melilite with subordinate wollastonite. The rocks are usually vesicular, the vesicles being filled with white zeolites. The only other macroscopically distinguishable minerals are magnetite and some pyrrhotine.

Thin sections of the rocks show at once that the preponderating mineral is melilite. Titanaugite is rarely met with, and even when present is extremely subordinate. Its presence in some of the rocks, however, links them to the titanaugite-melilite-rocks already described. Of other minerals, perovskite is the most constant, while wollastonite, aegirine, and magnetite frequently occur. Apatite, calcite, various zeolites, including thomsonite, and the new mineral scawtite, are often present in the sections. Nepheline is not common and never figures as a major constituent. In addition to cebollite as an alteration product of the melilite, grossular and a green fibrous monoclinic pyroxene are developed in some of these rocks as late products of the degradation of melilite.

Melilite is readily recognized by its brown to honey-yellow colour and its vitreous inclining to resinous lustre. It builds crystals up to $1\frac{1}{2}$ inches in diameter. The melilite previously analysed and described[1] came from these melilite-rocks. The dominance of melilite in these rocks is such that the remaining minerals may correctly be said to occupy the interspaces between the large melilite crystals. It is clear that much of the melilite had crystallized before other minerals were deposited. Only perovskite appears as inclusions

[1] C. E. Tilley, Geol. Mag., 1929, vol. 66, pp. 347–353.

within them, and then only in the peripheral parts of the crystals. Perovskite in this position is often allotriomorphic, as if it had undergone some resorption, but in the interspaces it appears in well-shaped octahedra of a brown to grey-brown colour. Birefringence is distinct and complex lamellar twinning always present. This twinning is of the usual type on (110), while the cubic cleavage is not infrequently well developed. Magnetite is a constant mineral in the interspaces between the melilites, and is often well crystallized, but wollastonite is very variable in amount. It is often associated with highly pleochroic aegirine at the edge of the large melilites. The fibres of aegirine spring from the boundary of the melilite and may become part of the periphery of a vesicle into which they extend amidst calcite and thomsonite. Apatite attains larger dimensions in these rocks than elsewhere, and may reach a millimetre or more in length. Nepheline is not common, but in some of the rocks appears with the wollastonite. It is usually partly, sometimes wholly, converted to thomsonite.

A striking development of grossular garnet is met with in some of the rocks. It quite clearly belongs to a late hydrothermal stage of the consolidation. The development of this mineral as colourless or yellowish grains takes place at the edge of the melilite, especially where this abuts against a vesicle, and spreads inwards until almost the whole of the melilite is converted. The garnet may be accompanied by a fibrous green pyroxene of high extinction-angle, either intermixed with it or placed exteriorly to the garnet zone. Both garnet and pyroxene are often exceedingly fine-grained. The textural relations indicate that this conversion must be relegated to a very late stage in the rock history. The late development of garnet at the expense of melilite has previously been described by Törnebohm (1882), Larsen (1914), and Kranck (1928). Its occurrence at Scawt Hill together with a green pyroxene deserves closer study and may well form a separate investigation.

Among the complex products which arise from the alteration of melilite is the recently described new mineral, scawtite.[1] This is found in intimate association with the melilite of the melilite-rich hybrid rocks, and is typically a constituent of some of the late formed vesicles. The minerals associated with it in the vesicles are chiefly calcite and thomsonite. In some cases the mineral forms minute venules cutting through the melilite, suggesting that it is formed in

[1] C. E. Tilley, Min. Mag., 1930, vol. 22, pp. 222–224.

part by attack of residual solutions upon the melilite itself. All the evidence clearly indicates that scawtite is among the latest products of consolidation of the hybrid rock.

An analysis of a typical melilite-rock is given on p. 448. The rock carries, in addition to the dominant melilite, wollastonite, perovskite, magnetite, pyrrhotine, apatite, calcite, and needles of aegirine springing from the melilite into vesicles full of thomsonite. Nepheline is absent. The original analysis omitting water and corrected to 100% is set down below. Perhaps its most striking characteristic is the low MgO content (1·06 %) and high iron. In these features it resembles the analysis of the nepheline-dolerite already given. The interpretation of this analysis will be deferred till the genesis of these rocks is considered.

	(1)	(2)	(3)
SiO_2	33·53	37·20	44·63
Al_2O_3	12·04	11·59	13·90
Fe_2O_3	9·83	3·94	4·73
FeO	8·46	10·75	12·90
MgO	1·22	1·46	1·75
CaO	28·31	28·56	14·27
Na_2O	2·51	3·38	4·06
K_2O	0·22	0·68	0·82
TiO_2	2·50	1·59	1·91
P_2O_5	0·78	0·52	0·63
Etc.	0·60	0·33	0·40
	100·00	100·00	100·00

(1) Melilite-rock, omitting water and corrected to 100 %.
(2) 100 parts nepheline-dolerite plus 20 parts CaO.
(3) Nepheline-dolerite, omitting water and corrected to 100 %.

Genesis of the Assemblages.

In the light of the petrographic data set forth in the previous sections, and the analyses of the chief mineral assemblages of the hybrid zone, the nature of the processes by which these rocks came into being may be more closely considered.

It has been noted that the predominant rock of the hybrid zone is a pyroxenite which can be traced in all its stages of development from the olivine-dolerite. An increase in the amount of pyroxene is accompanied by a reduction in olivine and plagioclase. The former is the first to disappear completely, and ultimately there results, close to the junction, a grey-black rock composed almost wholly of pyroxene, but usually with a little interstitial plagioclase and zeolite

(thomsonite principally). The mutual relations of this rock, the chalk, and the dolerite make it clear that there has been a notable amount of assimilation along the chalk contact, and in places undigested relics of flint nodules can be recognized in this hybrid zone. The analyses of the dolerite and the pyroxene-enriched rock indicate that addition of lime alone is not sufficient to change the dolerite to the pyroxene-rich rock. If to the former some silica as well as lime be added, e.g. in the proportions 100 : 6 : 8·5, the accordance is good (p. 461), except in the case of the oxides FeO and Na_2O. The process would, therefore, appear to involve some selective diffusion.

The pyroxene of the olivine-dolerite has been shown to be a hypersthene-bearing type, such as is common to magmas of 'plateau basalt' type. The pyroxene of the pyroxenite, of which an analysis has been given, contains, on the other hand, 90% of diopside-hedenbergite molecules and only 2·3% of hypersthene molecules. In the formation of the pyroxene-rich types the assimilated lime has been used in converting the hypersthene and olivine molecules of the dolerite to diopsidic pyroxene.

From a graphical construction containing the two rock analyses, the possible compositions of the material to convert olivine-dolerite to the pyroxene-rich rock can be readily ascertained. If, as seems justifiable, the material added is limited to some combination of lime and silica, then some oxides must be removed—in other words, there is selective diffusion and the surrounding liquid is enriched by them. The simplest case is that where the projected curves for magnesia and alumina approach zero. The composition of the material added for this point is for 100 parts of olivine-dolerite, SiO_2 3·06, CaO 7·40, while FeO 2·20 and Na_2O 0·58 must be abstracted. If more lime relative to silica is added, then notably alumina, and some ferric oxide and magnesia, must be abstracted in addition. The surrounding liquid must be enriched in iron relative to magnesia, however, and this fact is brought out in the relative Fe/Mg values in the two analyses—olivine-dolerite Fe/Mg = 1·6, pyroxene-rich dolerite Fe/Mg = 1·25. (This relation is still more strongly emphasized in the pyroxenite proper, the analysis of the pyroxene of which has Fe/Mg = 0·71.)

To give mineralogical expression to these facts one may conceive pyroxene-enrichment to result from reactions as follows :

(1) $(Mg,Fe)SiO_3 + CaO + SiO_2 \longrightarrow Ca(Mg,Fe)(SiO_3)_2$.

(2) $MgSiO_3 + FeSiO_3 + Fe_2O_3 + CaO \longrightarrow CaMg(SiO_3)_2 + Fe_3O_4$.

The second reaction provides one possible way in which an enrichment of the residual liquid in iron can come about. It is noteworthy that in many of the pyroxenites, iron-ores are singularly scanty (p. 450).

	(1)	(2)	(3)	(4)	(5)
SiO_2	46·77	46·77	48·05	47·50	47·58
Al_2O_3 ...	14·13	14·93	16·34	15·19	15·19
Fe_2O_3 ...	2·15	2·20	2·48	2·30	2·24
FeO	7·29	5·65	8·43	5·79	5·75
MgO ...	7·53	7·87	8·71	8·09	8·01
CaO	17·78	17·87	11·98	17·97	17·98
Na_2O ...	1·91	1·50	2·21	1·51	1·52
K_2O	0·30	0·29	0·35	0·32	0·29
TiO_2	1·0	1·06	1·12	1·04	1·07
Etc.	—	2·51	0·33	0·29	0·37
		100·65	100·00	100·00	100·00

(1) Mixture of olivine-dolerite : SiO_2 : CaO = 100 : 6 : 8·5.
(2) Pyroxene-rich dolerite.
(3) Olivine-dolerite, analysis corrected to 100 % after removal of water.
(4) Calculated composition of a mixture consisting of 100 parts of (3) plus 3·06 SiO_2, plus 7·40 CaO, minus 2·20 FeO, minus 0·58 Na_2O (corrected to 100 %).
(5) Pyroxene-rich dolerite, analysis corrected to 100 % after removal of water.

The reaction by which olivine ultimately disappears remains to be considered. Its conversion to diopsidic pyroxene involves participation of silica as well as added lime. It appears not improbable that some of the silica needed for the reaction may be obtained from the albite molecule of the plagioclase, nepheline molecules being stored up in the liquid:

$$3NaAlSi_3O_8 + 4CaO + 2Mg_2SiO_4 \longrightarrow 4CaMg(SiO_3)_2 + 3NaAlSiO_4.$$

That an alkali orthosilicate is present in the liquid is clearly evident from the common presence of thomsonite ($(Ca,Na_2)Al_2Si_2O_8.2\frac{1}{2}H_2O$) as an interstitial zeolite.

The formation of the pyroxenites is accompanied by enrichment of the surrounding magma in iron and soda. Such magma gives rise to the augite-plagioclase-rocks, devoid of olivine and characterized by abundant plagioclase and a strongly-coloured pyroxene, richer in iron and distinct from the pyroxene of the pyroxene-rich dolerites and pyroxenites. Already in some of the pyroxenites, the beginning of this process can be traced in the narrow shell of strongly-coloured (brown to red-brown) pyroxene which mantles the large greyish pyroxenes where they are in contact with interstitial zeolite.

The incorporation of further lime in this iron- and soda-enriched magma leads to more fundamental changes. The plagioclase now begins to be resorbed and becomes mantled by nepheline. The pyroxene acquires a distinctly red-brown and purplish tint and has markedly different optical properties from those of the pyroxenes of the pyroxenites. The process of replacement of plagioclase with its resorbed borders surrounded by nepheline is admirably illustrated in the thin sections, and all gradations between an augite-plagioclase-rock and an augite-plagioclase-nepheline(hydronephelite)-rock can be traced. In some cases wollastonite is simultaneously precipitated, but it is more common in more intensely hybrid types.

Throughout these changes there is clearly an enrichment of the pyroxene in titanium, indicated in the purplish tint which it more and more assumes. What is the fate of the plagioclase ? The production of nepheline is clearly a desilication of the albite molecule in the presence of lime. The fate of the anorthite in this resorption is manifest when the nature of the titaniferous pyroxene is investigated. The analysis already given of the titanaugite from the melilite-bearing nepheline-dolerite shows that the pyroxene contains excess lime and alumina (23·6 % CaO, 10·3 % Al_2O_3), which in the molecular composition can be expressed alternatively as 10·1 % $CaSiO_3$, 10·3% Al_2or O_3, as 19·0% $CaAl_2SiO_6$. The norm of the analysis shows 26·46 % of anorthite and 11·24 % of larnite. The meaning of the resorption of the plagioclase is clear : it gives place to nepheline and a lime-alumina-enriched pyroxene, which characterize these nepheline-bearing rocks. With excess lime the formation of melilite begins. This is especially noted at the immediate junction of the augite-plagioclase-rocks with the altered chalk.

The resulting rocks are titanaugite-melilite-plagioclase-(nepheline) assemblages passing into plagioclase-free varieties. The melilite is produced partly at the expense of titanaugite and plagioclase or nepheline. The rocks bear large crystals of both titanaugite and melilite, but there is clear evidence that melilite is the later crystallized product, and bears a reaction relation to the titanaugite. However large the titanaugite crystals they never enclose melilite. On the contrary, melilite crystals may be seen to enclose rounded and corroded crystals of the titanaugite, though it is not to be inferred that melilite is not also precipitated directly from the liquid. The titanaugite contains but insignificant quantities of alkalis ; the melilite, on the other hand, despite its high content of lime, must

be considered an alkali mineral. The analysed material shows 3·93 % Na_2O, and quantities of a like order are characteristic of ordinary humboldtilites. Molecularly this soda percentage corresponds to 10 % of the pure soda-sarcolite or lagoriolite. In the norm it is expressed as 19 % nepheline. The conversion of titanaugite (as solid or in solution) into melilite demands a reacting sodic liquid which is here available indirectly or directly as albite in plagioclase or as nepheline. This making over of plagioclase and pyroxene into melilite may be expressed by reactions such as:

(1) $CaMg(SiO_3)_2 + CaO \longrightarrow 2CaO.MgO.2SiO_2$.
(diopside) (åkermanite)

(2) $2(CaAl_2Si_2O_8) + 3CaO \longrightarrow 2CaO.Al_2O_3.SiO_2 + 3CaO.Al_2O_3.3SiO_2$.
(anorthite) (gehlenite) (pseudo-sarcolite)

(3) $CaAl_2SiO_6 + 2CaO + SiO_2 \longrightarrow 3CaO.Al_2O_3.3SiO_2$.
(Wahl silicate) (pseudo-sarcolite)

The evident desilication of the albite molecule, which gave rise to the nepheline in the nepheline-dolerite type, is now a desilication with orthosilicate entering the melilite molecule as soda-sarcolite ($3Na_2O.Al_2O_3.3SiO_2$); excess alumina and silica with lime yielding more pseudo-sarcolite and wollastonite, which is so common as an accessory in these rocks. Such soda as is not incorporated in the melilite crystallizes out as nepheline. Melilite thus accumulates at the expense of pyroxene, plagioclase, and nepheline. In the extreme examples, where plagioclase is completely absent, wollastonite is most abundant.

The Melilite-rocks.—The general absence of titanpyroxene and the presence of aegirine and perovskite render these assemblages of special interest. They are, moreover, extremely restricted in their distribution, being found as small lenses and patches, usually surrounded by the metasomatized chalk. They have clearly arisen from magmatic solutions reacting with chalk, and are examples of extreme hybrids. It must be pointed out that these rocks are not to be confused with the metasomatized chalk bearing a gehlenitic melilite associated with spurrite, &c. They are clearly related to the titanaugite-melilite-rocks, as is proved by their texture, their occurrence with sharp junctions against the altered chalk, and the very occasional presence of small amounts of titanaugite in some of them. Moreover, they are rich in wollastonite, a mineral which is restricted to the borders of flint nodules in the endogenous contact-zone.

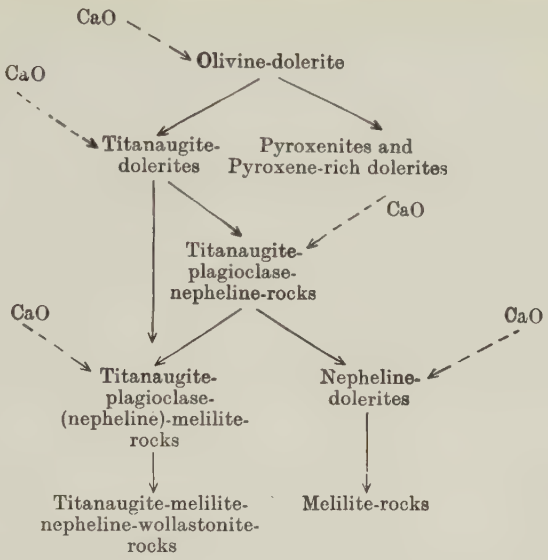
The analysis of a typical assemblage (p. 448) is especially remarkable for its exceedingly low magnesia compared to iron oxides and the relatively high soda and titania, considering the extreme amount of lime assimilation that has taken place. It is clearly not a direct hybrid between olivine-dolerite and chalk, for it contains as much soda as this rock. In its Fe/Mg ratio and content of titania and soda, its relation to the analysed nepheline-dolerite is made clear. Reference to the table on p. 459 shows that this melilite-rock is closely comparable to a mixture of 100 parts of nepheline-dolerite and 20 parts of CaO. Somewhat lower Na_2O and higher iron oxides characterize the melilite-rock, and it is enriched in TiO_2. The analysis, however, supports the conclusion that these assemblages are essentially a product of interaction of a residual alkali liquid (comparable to the analysed nepheline-dolerite) with limestone.

The formation of the predominant melilite and wollastonite results from an interaction in the liquid of titanaugite, nepheline, and CaO. The titanium of the nepheline-dolerite magma is precipitated along with melilite as perovskite, which appears for the first time in these rocks. In the nepheline-dolerite the titanium is held in the titanaugite. The residual liquid left after the precipitation of melilite was enriched in ferric oxide, which is abundantly precipitated later, as magnetite, in the interspaces, together with apatite, wollastonite, and aegirine, the crystallization of which results from a reaction between alkali silicate and the concentrated ferric oxide. The formation of aegirine is even extended into the vesicle stage, for it is found projecting from the borders of vesicles into the thomsonite of the interior.

Summary.

The course of assimilation and differentiation illustrated in the rock assemblages may be schematically represented in the following diagram (p. 465). The important part that complex pyroxenes play in the genesis of these assemblages will have become apparent from the preceding discussion.

Assimilation of lime by the olivine-dolerite magma leads first to the formation of pyroxene-rich dolerites and ultimately pyroxenites, by conversion of the hypersthene molecule of the augite and conversion of olivine to monoclinic pyroxene. This process is accompanied by enrichment of the pyroxenite in Mg relative to Fe. The liquid is



correspondingly enriched in Fe and this is one of the most striking chemical features of the rock series, as given below:

	Fe/Mg.
Pyroxenite (Pyroxene)	0·71
Pyroxene-rich dolerite	1·25
Olivine-dolerite	1·6
Titanaugite-melilite-rock	8·3
Nepheline-dolerite	13·0
Melilite-rock	19·0

The formation of the pyroxene-rich rocks leaves a magma enriched in plagioclase, soda, and iron (strongly), which corresponds to the olivine-free augite-dolerites with their dark-coloured augites. Further assimilation of lime leads to the formation of an augite-plagioclase-nepheline-rock, in which the evidence for the resorption of plagioclase is well seen, giving place to nepheline and a titaniferous lime-augite rich in alumina.

These assemblages are limited to the hybrid zone, and occur in segregatory patches and even in small veins, pointing to a later consolidation and a mobility superior to that of the pyroxenite type. In them areas composed almost wholly of titanaugite and nepheline (hydronephelite) give the nepheline-dolerite assemblage.

More intense absorption of lime at the immediate contact intro-

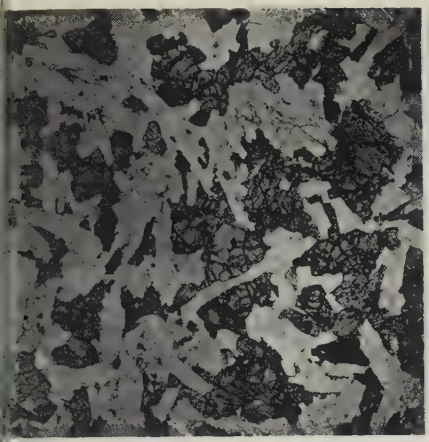
duces a new mineral among the crystallizing products, viz. melilite. This may arise primarily in the liquid from pyroxene and plagioclase molecules and also by a reaction of already crystallized pyroxene (which becomes resorbed) with the liquid. Ultimately all the plagioclase is used up in the production of melilite, or titanaugite and nepheline, and a melilite-titanaugite-rock, usually with nepheline commonly partly converted to thomsonite, is produced.

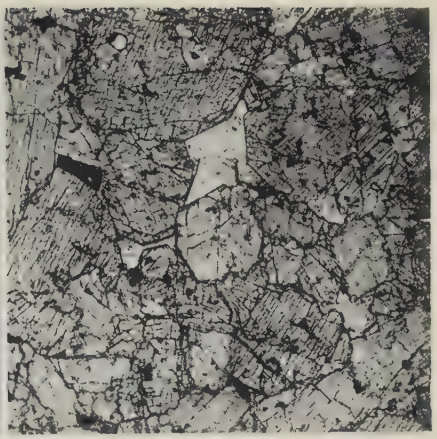
Lastly, the melilite-rocks, with their constituent wollastonite, perovskite, and aegirine, arise by interaction of lime and an alkali magma of nepheline-dolerite composition. It is only in these titanaugite-free rocks that perovskite figures as a rock constituent.

The conversion of limestone into lime-silicates in solution in igneous magma is undoubtedly a strongly endothermic process. It is in harmony with this fact that we find the zone of hybrid rocks is limited and local in its distribution. It is clear, however, that sufficient heat was available to incorporate carbonate into silicate solution with the precipitation of abundant diopsidic pyroxene and a resultant modification of the residual liquid. The nature of the assemblages of the exogenous contact-zone and the occurrence of wollastonite with basic plagioclase in place of grossular in the hybrid zone are additional features which point to a high temperature at the contact. It will be remembered that grossular is formed only at a late stage of the reaction process, corresponding to lower temperatures, and then at the expense of melilite. In fact, the series titanaugite-melilite-grossular is a reaction series in the same sense that augite-hornblende-biotite forms a reaction series in normal differentiation. The coarse grain-size of the hybrid zone, together with its vesicular character, is a very striking feature. The carbon dioxide derived from the assimilation of the chalk has, doubtless, assisted in decreasing the viscosity of the melt and permitted the free growth of comparatively large crystals, besides being responsible for the abnormal development of vesicles formed at a late stage of the consolidation.

In conclusion, we may add that the production of a basic alkali residuum in the manner detailed in the foregoing is unmatched among the described occurrences of alkali-rocks. The occurrence of a leucite-bearing zone surrounding inclusions of limestone from pyroxene-andesite at the volcanic centre of Merapi, Java, described by Brouwer,[1] has not yet been clearly worked out to yield any con-

[1] H. A. Brouwer, Proc. Roy. Acad. Amsterdam, 1928, vol. 36, p. 492.





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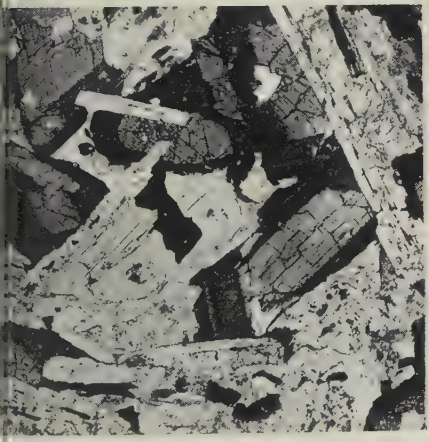

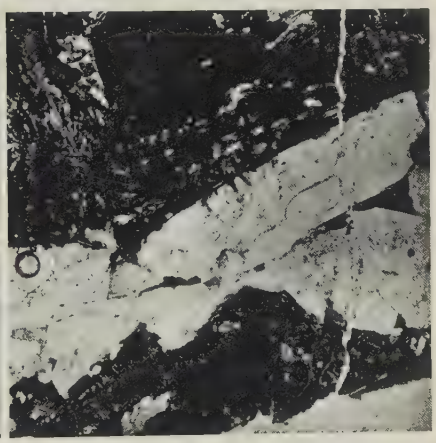

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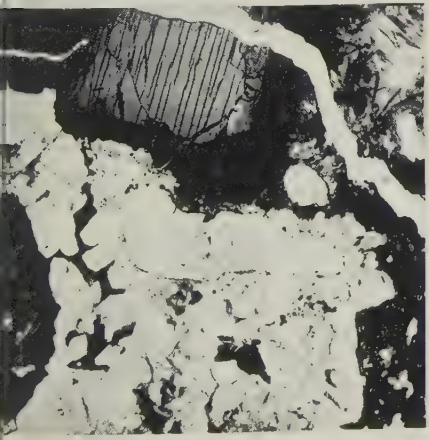

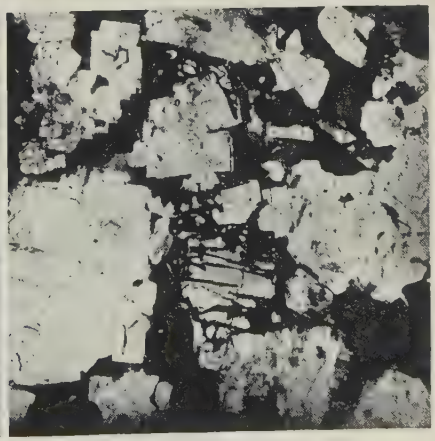

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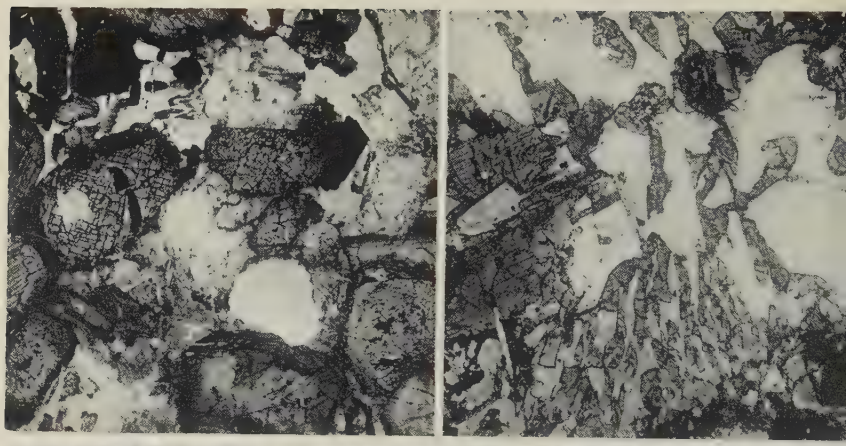
C. E. Tilley and H. F. Harwood: Dolerite-Chalk Contact of Scawt Hill, Co. Antrim.



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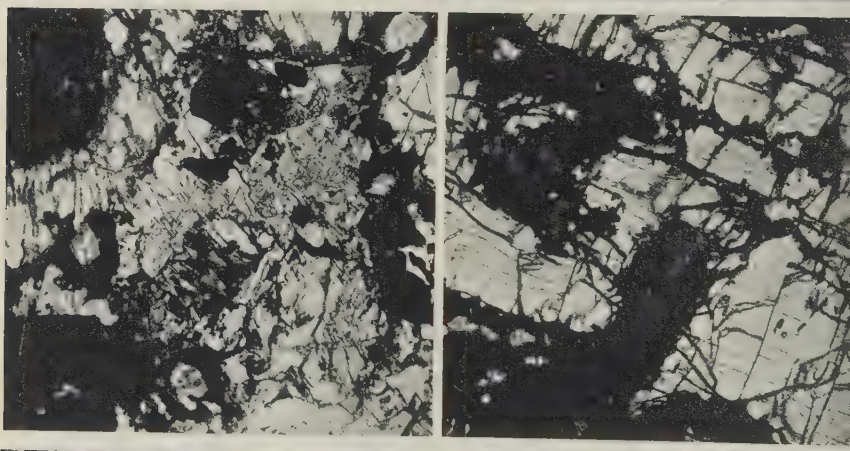

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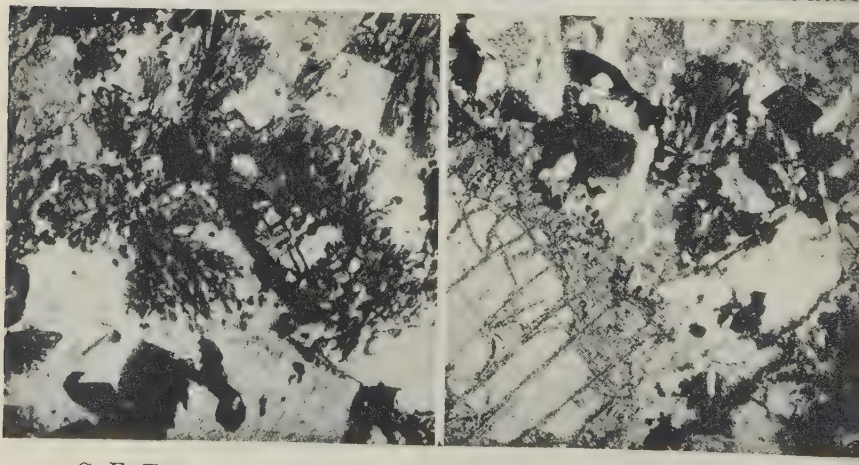

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C. E. Tilley and H. F. Harwood: Dolerite-Chalk Contact of Scawt Hill, Co. Antrim.

cise idea of the manner of production of this alkali-rock. These two occurrences, among others, have been used by Shand,[1] in a recent paper, to support the assimilation hypothesis of the origin of alkali-rocks. To this suggestion the writer would strongly demur. Rather is the Scawt Hill contact-zone, with its very limited hybrid zone and dominance within it of pyroxene-rich dolerite and pyroxenite assemblages, to be taken as an example of the restricted potentiality of igneous magma to generate alkali types by assimilation.

Explanation of Plates XVII and XVIII.

Photomicrographs of thin sections of rocks from the dolerite-chalk contact of Scawt Hill, Co. Antrim. (Magnification ×22.)

Fig. 1. Olivine-dolerite. The typical rock of the intrusion: olivine, augite, labradorite, and iron-ores, with subophitic texture.

Fig. 2. Pyroxenite. Idiomorphic diopsidic pyroxene with some interstitial labradorite and thomsonite. The labradorite in process of replacement by thomsonite. Note the paucity of iron-ores.

Fig. 3. Wollastonite-bearing augite-dolerite. A large wollastonite crystal enclosing magnetite occupies the centre of the field. Zoned brown augite, plagioclase, sphene, iron-ores, and interstitial thomsonite.

Fig. 4. Titanaugite-melilite-rock. Showing resorption of plagioclase (centre) mantled by nepheline, which borders a large altered melilite crystal enclosing titanaugite.

Fig. 5. Titanaugite-melilite-rock. Showing resorption of plagioclase to give nepheline. Altered melilite, zoned titanaugite, and vesicles of thomsonite.

Fig. 6. Titanaugite-nepheline-melilite-(plagioclase)-rock. The clear idiomorphic crystals are nepheline partly wrapped around by titanaugite and melilite. Resorbed plagioclase is present in adjacent parts of the section.

Fig. 7. Titanaugite-plagioclase-nepheline-rock. Showing resorption of plagioclase to give nepheline (above the cavity). Intergrowths of augite and nepheline are also visible against resorbed plagioclase at the top of the photograph.

Fig. 8. Nepheline-dolerite. Intergrowths of titanaugite and nepheline (in part changed to hydronephelite), iron-ores, and prisms of apatite.

Fig. 9. Titanaugite-melilite-wollastonite-rock (contact). The photomicrograph shows the junction of the hybrid rock with the altered chalk (at left-hand top corner) against which follows a zone of melilite passing out into titanaugite, and a finger-like intergrowth of wollastonite and thomsonite. Pseudomorphs of thomsonite after nepheline are seen at the bottom right corner.

Fig. 10. Titanaugite-melilite-wollastonite-nepheline(thomsonite)-rock. Showing a large tabular crystal of melilite enclosing rounded and resorbed grains of titanaugite.

[1] S. J. Shand, Geol. Mag., 1930, vol. 67, p. 415.

Fig. 11. Titanaugite-melilite-nepheline-rock. The centre of the field is occupied by a resorbed crystal of melilite forming a nucleus to a feathery aggregate of green augite. Large crystals of titanaugite are seen below to the left. The clear ground is thomsonite after nepheline, and wollastonite is seen in the top left corner.

Fig. 12. Melilite-rock. A large melilite crystal with altered borders (cebollite) is seen on the left. The clear areas represent wollastonite, while much aegirine and magnetite are present. These wollastonite-aegirine-magnetite areas occur as an interstitial base between the large melilite crystals.

The distinction of analcime from leucite in rocks by X-ray methods.

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[Read January 13, 1931.]

SINCE W. Lindgren [1] first detected the presence of microphenocrysts of analcime in basalt, many observers have recorded this mineral as a constituent of igneous rocks, but there is some difficulty in distinguishing between analcime and glass and between analcime and leucite in thin rock-sections. For instance, H. Rosenbusch [2] identified the interstitial colourless isotropic material in monchiquites as glass, whereas L. V. Pirsson [3] showed it to be analcime. H. S. Washington [4] showed that basalts from Sardinia, previously thought to be leucitic, contain phenocrysts of analcime. A. Lacroix [5] also found, in his study of north African basaltic lavas, that in many cases so-called leucite-lavas actually contain analcime and not leucite. More recently, Dr. F. Dixey and Mr. W. Campbell Smith [6] have described, associated with phonolites and kenytes from the Lupata Gorge, Zambezi River, Portuguese East Africa, lavas containing phenocrysts of analcime up to 1½ cm. in diameter. These lavas are compared with blairmorite, a volcanic rock from Alberta 'characterized by dominant phenocrysts of analcite in a matrix composed of analcite, alkali feldspar, and alkali-pyroxene, with titanite, melanite, and nephelite. . . .' [7] The analcime in the lavas from the Lupata Gorge

[1] W. Lindgren, Proc. California Acad. Sci., 1890, ser. 2, vol. 3, p. 52.

[2] H. Rosenbusch, Mikroskopische Physiographie der massigen Gesteine, 3rd edition, 1896, vol. 2, p. 539.

[3] L. V. Pirsson, Journ. Geol. Chicago, 1896, vol. 4, p. 679.

[4] H. S. Washington, Journ. Geol. Chicago, 1914, vol. 22, p. 742.

[5] A. Lacroix, Compt. Rend. Acad. Sci. Paris, 1924, vol. 178, pp. 529–535. [Min. Abstr., vol. 2, p. 309.]

[6] F. Dixey and W. Campbell Smith, Geol. Mag. London, 1919, vol. 66, p. 256. [Min. Abstr., vol. 4, p. 224.]

[7] J. D. MacKenzie, The Crowsnest volcanics. Canada Geol. Survey, Mus. Bull. no. 4, Geol. Ser. no. 20, 1914, p. 27.

is described as 'quite isotropic and pale-yellow in thin section, and shows traces of twin-lamellae often seen in leucite, but determination of its density (2·2–2·3), refractive index (about 1·48), and chemical constituents proves it to consist wholly of analcite'. From the area immediately south of the district described by Dr. F. Dixey, near the Fidzi River, F. P. Mennell [1] has recorded as pseudomorphous after leucite 'porphyritic crystals 2–5 mm. across of a rather yellowish greasy-looking appearance', which, from his description, seem to correspond to the phenocrysts in the blairmorite recorded by Mr. W. Campbell Smith as analcime. Whether these phenocrysts represent original leucite or primary analcime, it is important to place their identification beyond doubt.

X-ray methods afford a ready and certain means for mineral determination, and it is now proposed to apply them to confirm Mr. W. Campbell Smith's identification of the analcime phenocrysts. It is interesting to note here that X-ray methods would also decide the problem of interstitial analcime referred to above. Not only could the two other possible interstitial minerals, sodalite and leucite, be distinguished from analcime, but a direct proof would also be given of the crystalline or glassy nature of the material. Laue photographs have already been used by the author in distinguishing small nepheline phenocrysts of low refractive index from felspar in thin rock-sections.[2] Apart from identification, the Laue photographs in this case yielded values of the axial ratio and also the relative orientation of phenocrysts in the same section. A Laue photograph of a substance possessing cubic symmetry would constitute identification only as regards the distribution and intensities of the spots.

In applying X-ray methods to the supposed analcime phenocrysts of the blairmorites from the Lupata Gorge, the possibility of twinning and the cubic symmetry of analcime suggested the powder method rather than any other. A fragment of a phenocryst, previously studied by Mr. W. Campbell Smith, was finely powdered after a preliminary density determination by the flotation method (d 2·29). The measurements of the lines of the powder photograph are given in table I, together with data from powder photographs of analcime from the Cyclopean Islands, Sicily, published in a paper on the

[1] F. P. Mennell, Geol. Mag. London, 1929, vol. 66, p. 536. [Min. Abstr., vol. 4, p. 225.]

[2] F. A. Bannister, Abstr. Proc. Geol. Soc. London, 1929–1930, 1930, p. 104.

structure of analcime by Mr. W. H. Taylor.[1] The data are in complete agreement, not only as regards the position of the lines, but also their approximate relative intensity. A further powder photograph of analcime from the Cyclopean Islands was taken for direct comparison, and it was found that the lines of the analcime phenocryst photograph coincided exactly. Also, as table I shows, there are no visible lines present other than those to be expected from analcime.

Corresponding data for leucite do not appear to have been published. To complete the work, therefore, a small clear crystal of leucite from Monte Somma, Mt. Vesuvius, Italy, was powdered and a photograph taken. The leucite and analcime photographs are readily distinguishable. The measurements of the leucite powder photograph are given in table II. An attempt has been made to assign indices to the diffracting planes. For this purpose a small platy fragment of a leucite crystal was selected from the same specimen used for the powder photograph and a Laue photograph taken perpendicular to the plate. The pseudo-cubic pattern obtained suggests that the plane of the plate is parallel to the face (100). Between crossed nicols the plate shows the characteristic twin-lamellae parallel to the (110) faces, crossing each other approximately at right angles. Rotation photographs were then taken about the [100], [010], [001], [011], and [111] axes. The fragment appears to possess orthorhombic symmetry and the photographs indicate a unit body-centred cell whose edges are $a = 12{\cdot}95$, $b = 13{\cdot}12$, $c = 13{\cdot}74$ Å., the limits of error in each case being $\pm 0{\cdot}04$ Å. The density of the fragment is 2·47, and the unit cell contains 16 molecules of the type $KAlSi_2O_6$. The indices assigned to the lines of the leucite powder photograph are derived on the basis of the data from the rotation photographs. It has not, however, been possible to assign indices to all the lines. This, coupled with the fact that the fragment used for the rotation photographs shows twin-lamellae, leaves open the possibility of lower symmetry or different cell-edges for the unit cell of untwinned leucite. The data given in tables I and II do, however, show that powder photographs of leucite and analcime constitute a certain and ready means of distinction between the two minerals. There is no doubt, therefore, that the blairmorite phenocryst studied is analcime and is sensibly free from other components.

[1] W. H. Taylor, Zeits. Krist., 1930, vol. 74, pp. 1–19. [Min. Abstr., vol. 4, p. 369.]

Table I.

Data from powder photographs of analcime.

(*a*) Analcime phenocryst in blairmorite from Lupata Gorge, Zambezi River, Portuguese East Africa. (N724 = B.M. 1929,173,72.) $d = 2{\cdot}29$, unit cell-edge $a = 13{\cdot}70 \pm 0{\cdot}05$ Å.

(*b*) Analcime crystal from Cyclopean Islands, Sicily. (B.M. 1914,332). $d = 2{\cdot}27$, unit cell-edge $a = 13{\cdot}70 \pm 0{\cdot}05$ Å.

(*c*) Analcime crystal from Cyclopean Islands, Sicily. W. H. Taylor's data. Unit cell-edge $a = 13{\cdot}68 \pm 0{\cdot}04$ Å.

Observed diameters of the Debye-Scherrer rings. cm.		sin θ.			Observed intensities.		Indices of planes.
(*a*)	(*b*)	(*a*)	(*b*)	(*c*)	(*a*)	(*c*)	
1·70	—	0·140	—	0·138	*vs*	*vs*	(211)
1·93	—	0·159	—	0·159	*ms*	*m*	(220)
2·28*	—	0·188	—	—	*m*	—	(400)
2·48*	—	0·203	—	—	*m*	—	(400)
not observed	—	—	—	0·211	—	*vw*	(213)
2·735	—	0·224	—	0·226	*vvs*	*vvs*	(400)
3·10	—	0·254	—	0·253	*vw*	*vvw*	(420)
3·23	3·23	0·264	0·264	0·264	*vs*	*vs*	(233)
not observed	—	—	—	0·276	*w*	*w*	(422)
3·50	3·50	0·286	0·286	0·286	*m*	*ms*	(413)
3·78	3·79	0·307	0·309	0·308	*ms*	*ms*	(215)
3·90	—	0·317	—	0·320	*w*	*mw*	(440)
4.27	—	0·346	—	0·346	*ms*	*m*	(235)
4.48	—	0·362	—	0·365	*vw*	nil	(415)
4·70	—	0·379	—	0·382	*w*	nil	(613)
4·94	—	0·398	—	0·397	*w*	nil	(435)
5·03	5·04	0·404	0·405	0·406	*ms*	*m*	(640)
5·14	—	0·413	—	0·414	*m*	*m*	(633)
5·53	5·53	0·442	0·442	0·443	*ms*	*ms*	(237)
5·62	—	0·449	—	—	*m*	—	(800)
5·70	—	0·435	—	—	*m*	—	(417)
6·07	—	0·482	—	—	*m*	—	(831)
6·60	—	0·519	—	—	*w*	—	(219)
6·92	—	0·542	—	—	*m*	—	(239)
7·28	7·29	0·567	0·568	—	*ms*	—	(277)
7·56	—	0·586	—	—	*w*	—	(10.3.1)
7·71	—	0·596	—	—	*m*	—	(817)
7·90	—	0·608	—	—	*vw*	—	(10.4.0) ?
8·23	8·23	0·630	0·630	—	*m*	—	(639)
8·60	—	0·653	—	—	*w*	—	(866)
9·11	—	0·685	—	—	*w*	—	(10.5.5)
9·68	—	0·718	—	—	*w*	—	(10.8.0)

The diameter of the cylindrical camera = 6·04 cm. θ = glancing angle corresponding to Cu − K_α radiation, $\lambda = 1{\cdot}539$ Å., *s* = strong, *m* = medium, *w* = weak, *vs* = very strong, &c.

* These two lines are due to Cu − K_β and W − L_β radiation.

TABLE II.

Data from powder photograph of leucite, $d = 2{\cdot}49$, from Monte Somma, Mt. Vesuvius, Italy. (B.M. 53690.)

Diameters of Debye-Scherrer rings. cm.	sin θ.	Observed intensities.	Indices of planes.
1·40	0·115	*s*	(112)
1·75	0·145	*vs*	(211)
2·31*	0·190	*m*	(004)
2·49*	0·204	*m*	(004)
2·60	0·214	*w*	(123)
2·75	0·226	*vs*	(004)
2·90	0·237	*vs*	(400)
3·00	0·246	*w*	(303) ?
3·15	0·258	*w*	(042)
3·29	0·268	*s*	(420)
3·35	0·273	*s*	(233)
3·50	0·286	*vvw*	(242)
3·60	0·294	*s*	(215)
4·01	0·326	*s*	(404)
4·10	0·334	*w*	(440)
4·35	0·352	*w*	(235)
4·41	0·357	*w*	(253)
4·47	0·362	*m*	(532)
5·00	0·402	*vw*	(631)
5·19	0·417	*w*	(064)
5·34	0·428	*w*	(246)
5·40	0·432	*m*	(426)
5·60	0·447	*m*	(008) ?
5.80	0·462	*ms*	(417)
5·91	0·470	*w*	—
6·11	0·485	*m*	(280)
6·35	0·502	*m*	(660)
6·60	0·519	*m*	—
7·20	0·560	*m*	—
7·64	0·591	*w*	—
8·05	0·618	*ms*	—

The diameter of the cylindrical camera = 6·04 cm. θ = glancing angle corresponding to Cu—K_α radiation, $\lambda = 1{\cdot}539$ Å.

* These two lines are due to Cu—K_β and W—L_β radiation.

Chemical analyses of the zeolites show that the silicon to aluminium ratio in general varies considerably, and it is also known that the alkalis can be readily replaced without alteration of crystal form. Taylor has correlated the fairly constant silicon to aluminium ratio in analcime with the crystal structure obtained by X-ray methods.

He has also shown by powder photographs that substitution of the sodium by silver atoms does not alter the cell-size, but does affect the relative intensities of the X-ray diffractions. It has been possible owing to his work to note carefully in the X-ray photograph of the analcime phenocryst those lines which would be most affected by any replacement of the sodium atoms, and there is no indication of any apparent departure from the relative line-intensities of the normal analcime photograph. Primarily, the photographs now taken constitute a method of identification, and the most accurate measurements of intensity of X-ray diffractions do not compete in accuracy with chemical analysis. However, the present work, in conjunction with the refractive index value, indicates that the analcime phenocryst is probably of normal composition.

The interest in applying X-ray methods to the study of rocks lies not only in the identification of difficult cases, but in the possibility of studying any given mineral in rock-sections. With the object of seeing whether in the above case the Laue method or the oscillation method applied to a thin section of the analcime phenocrysts would yield satisfactory results, a Laue photograph of a small fragment of Lupata Gorge analcime was taken, using monochromatic radiation. The spots produced are large and rather diffuse ; their elongated shape indicates that they all correspond to monochromatic radiation and not to white radiation. Table III gives the measurements on this photograph and shows the presence of important analcime lines of table I. The phenocryst is not, therefore, a single crystal, but is made up of smaller individuals in sub-parallel position. Those individuals correctly oriented diffract the copper radiation and produce the relatively strong lines already noted. In addition, each individual produces its Laue pattern due to white radiation. These spots are very faint and small, and a background of these superposed Laue patterns can actually be observed on the plate. The powder photograph obtained when a crystalline substance is not sufficiently finely pulverized shows flecked Debye-Scherrer rings, and when the powder is yet coarser the rings are no longer continuous, but broken. The photograph of the phenocryst fragment under consideration is an extreme case of this latter type. In order to describe the photograph, not only the glancing angle θ is given for each spot, but also the angle of azimuth ϕ measured from a line through the centre of the plate arbitrarily chosen as horizontal. Table III shows the number of spots on any one ring and their corresponding ϕ values. There are several equal ϕ value intervals of

TABLE III.

Data from Laue photograph, using monochromatic radiation, of a fragment of analcime phenocryst in blairmorite from Lupata Gorge, Zambezi River, Portuguese East Africa (N724 = B.M. 1929,173,72).

Indices of planes observed.	sin θ.	θ.	Angles of azimuth ϕ.				
(211)	0·140	8°	79°	131°	—	—	—
(220)	0·159	9° 10′	0	131	—	—	—
(400)	0·224	13 3	0	19	38°	106°	270°
(233)	0·264	15 19	0	19	38	157	—
(413)	0·286	16 36	38	64	79	284	—
(215)	0·307	17 58½	79	106	122	140	157
(440)	0·317	18 30	64	79	—	—	—
(235)	0·346	20 15	190	205	229	350	—
(444)	0·395	23 16	44	166	339	—	—
(640)	0·404	23 49	222	232	270	339	—
(237)	0·442	26 14	42	160	—	—	—

θ = glancing angle corresponding to Cu—K_α radiation, λ = 1·539 Å.

Spots were also observed for the strongly reflecting planes (400), (233), (413), and (215), corresponding to W—L_{α_1} radiation, λ = 1·473 Å.

about 19° repeated on the plate. If the values of θ and ϕ be plotted stereographically, it is found that the strongly diffracting planes, e.g. (400) or (233), for these neighbouring ϕ values have an angular separation of 4° to 5°. It is probable, therefore, that the maximum tilt between neighbouring particles of the phenocryst is of the same order.

The analcime in blairmorites from the Lupata Gorge forms large icositetrahedra. Although the external form suggests a regular internal crystalline formation, the X-ray investigations have shown that the phenocryst is broken into coarse particles which are no longer perfectly alined, but show only a sub-parallel arrangement. Since the molecular weights of analcime and leucite are approximately equal, the molecular volumes are inversely as the ratio of the densities, namely, 2·5 : 2·3 respectively. If the analcime phenocrysts are pseudomorphs after leucite, the expansion of 1·09 by volume might not be sufficient to affect seriously the external form of the icositetrahedra.

The present work, therefore, is consistent either with the view that the phenocrysts are primary or that the analcime is pseudomorphous after leucite or a hypothetical soda-leucite. If the phenocrysts are primary, their sub-parallel arrangement may be due to irregularities of growth or to stresses imposed after crystallization.

Summarizing the above results, powder photographs have satisfactorily confirmed the identity of the analcime phenocrysts in blairmorites from the Lupata Gorge. A Laue photograph of a fragment of the phenocryst using monochromatic radiation has also yielded information on the crystalline aggregation of the phenocrysts.

In conclusion, I should like to thank Mr. W. Campbell Smith for suggesting this problem and for his continued help.

Communications from the Oxford Mineralogical Laboratory, No. XXVIII.

An occurrence of grunerite at Pierrefitte, Hautes-Pyrénées, France.

By Harry V. Warren, B.Sc., D.Phil.,
Queen's College, Oxford.

[Read January 13, 1931 ; communicated by Prof. H. L. Bowman.]

As grunerite is a somewhat uncommon mineral, and as its occurrence at Pierrefitte in association with lead and zinc ore is unusual, if not unique, it may be worth while to put on record the following notes on some material which I collected during an examination of the Pierrefitte deposits.

The name 'grunerite'[1] was originally given to a fibrous mineral approximating in composition to $FeSiO_3$ and occurring with magnetite and garnet at Collobrières in the dept. of Var, in the south of France, which was described by Gruner in 1847. It was originally supposed to be a pyroxene, but was later shown by Des Cloizeaux and Lacroix to belong to the amphibole group. A similar mineral occurs in the iron deposits of the Lake Superior district,[2] and elsewhere ; but it has not been recorded from the Pyrenees.

Mode of occurrence.

The mineral occurs at the Pierrefitte mine, near the village of Pierrefitte-Nestales, 10 miles south of Lourdes, in two forms, which are quite distinct: (i) as nearly the sole constituent of a grunerite-

[1] The name of the mineral is often erroneously spelt grünerite. The name grunerite (Grunerit) was given to it by A. Kenngott (Das Mohs'sche Mineralsystem, 1853, p. 69) in honour of E. L. Gruner, who first described it in 1847 (Compt. Rend. Acad. Sci. Paris, 1847, vol. 24, p. 794 ; Annales des Mines, Paris, 1848, ser. 4, vol. 14, pp. 284–301). Emmanuel Louis Gruner (1809–1883) was at that time professor at the École des Mineurs, St. Étienne, and afterwards Inspecteur Général des Mines, and professor at the École des Mines in Paris.

[2] A. C. Lane and F. F. Sharpless, Amer. Journ. Sci., 1891, ser. 3, vol. 42, p. 505. S. Richarz, Amer. Journ. Sci., 1927, ser. 5, vol. 14, p. 150. [Min. Abstr., vol. 3, p. 375.]

schist which overlies the ore-bodies; (ii) as distinct needles, either isolated or forming a network, in the ore.

Under the microscope the grunerite-schist resembles a normal amphibole-schist, but the rock itself is harder, tougher, and more massive, and, indeed, the term schist is hardly applicable, as the grunerite needles are matted together irregularly and there is little tendency to splitting. It is commonly associated with a carbonaceous schist, and the ore in its neighbourhood usually contains magnetite.

Where found in the ore, the grunerite is usually associated with galena, blende, chalcopyrite, magnetite, and pyrrhotine. However, it is in galena that the needle-like crystals are most in evidence.

Mineralogical properties.

Under the microscope the Pierrefitte grunerite is clear and colourless if free from other minerals, but in the mass it is frequently dirty white or grey. In polished specimens of the ore the grunerite sometimes shows a decided yellow tinge when viewed by reflected light. The individual needles are rarely a tenth of an inch in length and are usually much smaller.

The grunerite needles in the schist frequently show a core of an undetermined bluish-green mineral which possesses weak pleochroism, and appears to resemble a similarly related mineral in some of the Lake Superior grunerite.

The grunerite possesses perfect prismatic cleavage, and although most of the fragments were too small to measure, a few were large enough. The cleavage-angles on some of the larger fragments were measured. The fragments were then broken up and examined optically to see if their properties differed visibly from those of the finer material, but no differences could be discovered. The goniometer readings were not entirely satisfactory owing to imperfections on many faces. The measured cleavage angles varied from 53° 55′ to 54° 55′, the mean being about 54° 20′. The readings from the best fragment, which agreed well together, gave a somewhat larger mean angle, 54° 48′. Even this angle is considerably less than that of most varieties of amphibole.

The refractive indices were determined by the immersion method. Three mixtures of α-monobromnaphthalene and methylene iodide were made, to agree with α, β, and γ, respectively, and Miss M. W. Porter very kindly determined for me the indices of these mixtures by means of an Abbe-Pulfrich refractometer. Care was taken to

maintain a constant temperature during the final determinations. The results, with Na-light, are $\alpha = 1{\cdot}676$, $\beta = 1{\cdot}693$, $\gamma = 1{\cdot}707$, $\gamma - \alpha = 0{\cdot}031$. Using the approximate formula $\cos V_\alpha = \sqrt{(\beta-\alpha)/(\gamma-\alpha)}$, we find that $2V_\alpha = 84° 26'$. The plane of the optic axes is parallel to (010), and the acute bisectrix (α) emerges through (100). A direct determination of the optic axial angle was made with a grunerite needle mounted on a stage goniometer and immersed in a liquid mixture whose index coincided with β. This gave $2V = 84° 15'$. The close agreement between the observed and the calculated optic axial angle is doubtless accidental, but, nevertheless, it probably indicates that the indices of refraction are approximately correct.

In the same way the maximum extinction-angle ($c : \gamma$) in the prism-zone was found to be 13° 22′. Dispersion of the optic axes was not noticeable.

Chemical composition.

It was extremely difficult to separate the grunerite when occurring in the ore, and the separation was eventually only accomplished by boiling the crushed fragments of ore in aqua regia for several hours. This drastic treatment had no visible effect on the optical properties of the mineral, though it may possibly have affected slightly the chemical composition.

Chemical analyses of grunerite from the schist and from the ore were kindly made for me by Mr. E. G. Radley, of the Museum of Practical Geology, London. Owing to the presence of carbon, the analyses were complicated, and I am very grateful to Mr. Radley for the trouble which he took on my behalf. The results are given in columns I and II of the following table (p. 480), which shows also the analyses of grunerite from other localities.

The higher percentage of silica in the grunerite from the ore is probably due to a small amount of quartz which occurs in the ore. Some of the iron and some of the carbon may have been oxidized, and possibly a little of the former has gone into solution, as a result of the treatment with aqua regia. In the discussion and table dealing with the relation existing between the chemical composition and the optical properties the analysis of the grunerite from the schist will be used, as this was only treated with aqua regia for a short time.

The carbon can be seen as minute specks in nearly all the grunerite, and is partly responsible for the dirty colour. It remains as a black flocculent residue on solution of the grunerite in hydrofluoric acid.

Analyses of grunerite.

	I.	II.	III.	IV.	V.
SiO_2	46·42	49·11	48·53	47·17	43·9
TiO_2	0·15	0·12	—	—	—
Al_2O_3	0·25	1·81	1·02	1·00	1·9
Fe_2O_3	0·09	2·03	1·14	1·12	—
FeO	42·60	38·98	39·20	43·40	52·2
MnO	2·23	0·79	0·66	0·08	—
MgO	3·12	2·97	4·06	2·61	1·1
CaO	1·51	0·75	1·31	1·90	—
Na_2O	0·70	0·94	1·06	0·47	—
K_2O	0·43	0·64	0·19	0·07	—
H_2O	0·14 *a* 1·78 *b*	0·10 *a* 1·39 *b*	1·71 *c*	2·22	0·5
C	0·65	0·31	—	—	—
F	—	—	—	0·07	—
	100·07	99·94	98·88	100·11	99·6
Sp. gr.	—	—	3·44	3·518	3·713

a Below 105° C.; *b* above 105° C.; *c* above 110° C.

I. Pierrefitte, Hautes-Pyrénées, France (from schist). (Analyst, E. G. Radley.)

II. Pierrefitte, Hautes-Pyrénées, France (from ore). (Analyst, E. G. Radley.)

III. Mt. Humboldt, Lake Superior, Michigan, U.S.A. S. Richarz, loc. cit., 1927, p. 151.

IV. La Mallière, near Collobrières, Var, France. S. Kreutz, Sitzungsber. Akad. Wiss. Wien, Math. naturwiss. Kl., Abt. I, 1908, vol. 117, p. 910.

V. Collobrières, Var, France. E. L. Gruner, Ann. des Mines, Paris, 1848, ser. 4, vol. 14, p. 301.

Relation between chemical composition and optical properties.

These results agree, on the whole, with those of previous work,[1] namely, that the indices of refraction and the birefringence increase with an increase in the percentage of FeO and MnO. The birefringence and the index α of the Pierrefitte grunerite are not in complete accord with the above conclusion, but the discrepancies are small and there is clearly a general agreement.

The following table (p. 481) summarizes the data which are known at present. Neglecting other constituents, I have calculated the molecular percentages of $FeSiO_3$, $MnSiO_3$, $MgSiO_3$, and $CaSiO_3$.

It will be noticed that the Pierrefitte grunerite is high in $MnSiO_3$ and low in $MgSiO_3$ when compared with the grunerite from Mt. Humboldt. This may account for the slight discrepancy in birefringences. Both also contain considerably more $MnSiO_3$ than the

[1] S. Richarz, loc. cit., p. 153.

	Collobrières.[1]	La Mallière.[2]	Pierrefitte.	Mt. Humboldt.[3]
$FeSiO_3$	96·4	85·8	81·4	80·4
$MnSiO_3$	0·0	0·2	4·3	1·4
$MgSiO_3$	3·6	9·2	10·6	14·8
$CaSiO_3$	0·0	4·8	3·7	3·4
α	—	1·672	1·676	1·666
β	1·73*	1·697	1·693	1·684
γ	—	1·717	1·707	1·700
$\gamma-\alpha$	0·056	0·045	0·031	0·034
2V	50°	80–84°	84° 15′	85°
$c:\gamma$	11–15°	10–11°	13° 22′	14–15°

* Strictly $(\alpha+\beta+\gamma)/3$.

other grunerite and this may be due to the presence of the undetermined green mineral.

Origin of the grunerite.

Grunerite is supposed to have resulted from the metamorphism of ferrous carbonate in depth,[4] but there appears to be no evidence for such an origin in this area. It is possible that the carbon, which is present in the grunerite itself and in the neighbouring carbonaceous schist, has exerted a reducing action which has some bearing on the formation of the grunerite. The grunerite of the Krivoy Rog[5] in South Russia is also stated to be associated with carbonaceous schists. Quartz, which is rare at Pierrefitte, may have combined with the magnetite, in the presence of carbon, to form grunerite according to the equation :

$$C + 2Fe_3O_4 + 6SiO_2 = 6FeSiO_3 + CO_2.$$

This appears to be a possible explanation of the presence of grunerite at Pierrefitte. But it is probable that in different occurrences the mode of formation may not always have been the same.

[1] E. L. Gruner, loc. cit.; A. Lacroix, Bull. Soc. Franç. Min., 1886, vol. 9, p. 40.

[2] S. Kreutz, loc. cit.

[3] S. Richarz, loc. cit.

[4] C. R. Van Hise, A treatise on metamorphism. Monogr. U.S. Geol. Survey, 1904, no. 47, pp. 244, 834.

[5] F. Beyschlag, J. H. L. Vogt, and P. Krusch, The deposits of the useful minerals and rocks. Translated by S. J. Truscott, 1914–16, p. 1059.

Ephesite (soda-margarite) from the Postmasburg district, South Africa.

By F. Coles Phillips, M.A., Ph.D., F.G.S.,
Corpus Christi College, Cambridge.

[Read January 13, 1931.]

THE material on which the following description is based was presented by Dr. A. L. Hall to the Department of Mineralogy at Cambridge, and I am greatly indebted to him and to Prof. A. Hutchinson for affording me the opportunity of describing it. The first account of the occurrence was given by Dr. Hall,[1] recording from Aarkop, Magoloring, 'a beautiful delicately rose-coloured mica . . . in compact dark bluish-grey ore as thick, short, columnar aggregates not unlike little books of mica with pseudo-hexagonal outlines and showing the characteristic perfect basal cleavage . . . . the material was found on the higher slopes defining the west side of Martha's Kloof'. This description was amplified somewhat in a later publication,[2] with the addition of an analysis (see below). As noted therein the mineral also resembles that described by Chudoba[3] as a manganophyllite allied to the phlogopite group, but the fuller description given below reveals important differences.

The specimens which I have investigated consist of aggregates of pale pink to pinkish-brown crystals in mica-like platy or sometimes prismatic habit, apparently hexagonal, up to 13 mm. in diameter and 10 mm. in length, with a very irregular and corrugated prism-zone. The very good basal cleavage yields rather brittle cleavage-flakes. In very thick vertical sections the colour is pinkish-brown,

[1] A. L. Hall, The manganese deposits near Postmasburg, west of Kimberley. Trans. Geol. Soc. South Africa, 1927, vol. 29 (for 1926), p. 36. [Min. Abstr., vol. 3, p. 397.]

[2] L. T. Nel, The geology of the Postmasburg manganese deposits and the surrounding country. Geological Survey of South Africa, Pretoria, 1929, p. 81. [Min. Abstr., vol. 4, p. 232.]

[3] K. Chudoba, Über 'Mangandiaspor' und Manganophyll von Postmasburg (Griqualand-West, Südafrika). Centr. Min., Abt. A., 1929, p. 17. [Min. Abstr., vol. 4, p. 148.]

with, apparently, no pleochroism; in thin sections and cleavage-flakes it is colourless. Specific gravity = 3·00; hardness = 5—7, variable on different faces.

Chemical composition.—An analysis by H. G. Weall, F.I.C., of the Government Laboratories, Johannesburg, gave the figures in column I below. Those in column II were obtained in an independent partial analysis carried out by me to confirm the essential identity of the mineral.

	I.	II.
SiO_2	29·4	28·9
TiO_2	0·1	
Al_2O_3	50·6	51·6
Fe_2O_3	0·55	
FeO	0·35	
CaO	1·4	—
MgO	0·4	—
MnO	0·1	—
Na_2O	8·65	9·2
Li_2O	1·5	0·9
K_2O	trace	0·3
H_2O-	1·25	—
H_2O+ (ignition)...	5·3	—
F	0·2	—
	99·80	

Optical properties.—Cleavage fragments invariably show, at least in the marginal portions, a multiple lamellar twinning, the composition-plane being some face in the zone between the prism and basal plane, and inclined to the basal plane at moderate angles, giving undulose extinction in the different lamellae. Measurements on the universal stage establish the presence of more than one twin-law; in the most frequent the composition-plane makes an angle of approximately 66° with the basal plane. Twins on both (*hhl*) and ($h\bar{h}l$) are present in the same individual.

Untwinned portions show an acute bisectrix interference-figure, with Bx_a nearly perpendicular to the cleavage-plane, and a small axial angle. The plane of the optic axes is perpendicular to (010) of the hexagonal cleavage-flake; optic sign negative. Nothing was seen, despite careful search, of the optic anomalies described by Chudoba in his material. 2E for sodium-light varied in six measurements from 42° 32′ to 43° 8′, with dispersion 2V red less than 2V blue.

The intimate lamellar twinning makes accurate determination of the refractive indices somewhat difficult, but good results were finally obtained by the Kohlrausch total reflection method on a Hutchinson universal instrument, using an artificially-polished plate (natural cleavage-flakes were always too distorted to give sharp shadows). The figures thus obtained are:

$$\alpha = 1{\cdot}595,\ \beta = 1{\cdot}625,\ \gamma = 1{\cdot}627 \pm 0{\cdot}002,$$

whence $\gamma - \alpha = 0{\cdot}032$, 2V calc. $= 28°\ 32'$ (2E calc. $= 38°\ 54'$).

Structure.—I am indebted to Mr. J. D. Bernal for an X-ray examination, carried sufficiently far to determine a monoclinic pseudo-hexagonal structure, with approximate dimensions:

$$d_{(001)} = 9{\cdot}70,\ a = 5{\cdot}16,\ b = 8{\cdot}79\ \text{Å}.,$$

which resemble closely those of the micas, and suggest the presence of a silicon-oxygen sheet.[1]

Formula.—The analysis shows that the mineral is much more aluminous than any mica, as noticed by Dr. J. McCrae (L. T. Nel, loc. cit., p. 81). The mineral described by Chudoba as allied to the phlogopite group showed different optical properties, and, moreover, when fused with alkaline carbonates showed a significant manganese content.

If the above analysis is recalculated in terms of the atoms present, on a basis of O + F = 12, the following figures are obtained:

Si	1·94	
Al + Fe‴ + Li	4·37	
Fe″ + Mg + Mn	0·06	9·91
Na + Ca	1·20	
H	2·34	
O + F	12·00	

and the affinities of the mineral are with the margarite group. For margarite itself, L. Pauling[2] has suggested a formula which may be written $(OH)_2Ca_2Al_2(Al_2Si_2O_{10})$. The above figures agree with a proportion of oxygen to other atoms of 12 to 10, but Ca is largely substituted by Na, a substitution to be expected on structural grounds from the relative sizes of the ions. The mineral may be described as a soda-margarite; in general physical properties and optical orientation it closely resembles margarite, but differs from it in optic axial angle and in double refraction.

[1] W. L. Bragg, The structure of silicates. Zeits. Krist., 1930, vol. 74, p. 271.

[2] L. Pauling, Proc. Nat. Acad. Sci. U.S.A., 1930, vol. 16, p. 128. [Min. Abstr., vol. 4, p. 368.] Cf. W. L. Bragg, loc. cit., p. 272.

Discussion.—Material of closely similar composition was described by J. Lawrence Smith in 1851, under the name ephesite. The mineral was found associated with emery at Gumuch Dagh, near Ephesus, Asia Minor.[1] The name lesleyite was given by I. Lea in 1867 to material from Unionville, Pennsylvania, which Smith subsequently showed to be identical with his ephesite in composition, except for higher potash. The identity of these substances as species was later questioned by Brush,[2] who regarded them as mixtures containing corundum. Genth,[3] also, relying on incomplete decomposition on fusing with lime and ammonium chloride, estimated the free corundum at amounts as high as 20 %, but his bulk analysis of the whole agrees almost exactly with that of Smith. In the same paper he remarks that some analyses of margarite contain a considerable quantity of alkalis, especially soda, replacing the lime. As pointed out above, replacements of Ca by Na, and, perhaps, also by K, are to be expected from a structural point of view. It seems reasonable, therefore, to use the names ephesite and lesleyite as synonyms of soda-margarite and potash-margarite respectively. The most sodic margarite previously recorded in the literature appears to be the 'clingmanite' of B. Silliman,[4] containing 6·15 % Na_2O, with 9·87 % CaO.

[1] J. L. Smith, Amer. Journ. Sci., 1851, ser. 2, vol. 11, p. 59.

[2] G. J. Brush, Appendix I to fifth edition of Dana's Mineralogy, 1888, p. 18.

[3] F. A. Genth, Proc. Amer. Phil. Soc., 1873, vol. 13, pp. 387–390.

[4] B. Silliman, Amer. Journ. Sci., 1849, ser. 2, vol. 8, p. 383. Corrected analysis in 3rd edition of Dana's System of Mineralogy, 1850, p. 362.

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